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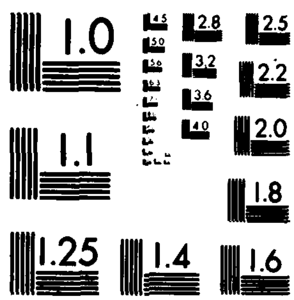
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The 15th Annual Meeting of the U. S. Army Corps of Engineers Aquatic Plant Control Research Program was held in Savannah, Georgia, on 17-20 November 1980, to review current research activities and to afford an opportunity for presentation of operational needs.

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PREFACE

The 15th Annual Meeting of the U. S. Army Corps of Engineers Aquatic Plant Control Program was held in Savannah, Georgia, on 17-20 November 1980. The meeting is required by Engineer Regulation (ER) 1130-2-412 paragraph 4c and was organized by personnel of the Aquatic Plant Control Research Program (APCRP), Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES).

The organizational activities were carried out and presentations by WES personnel were prepared under the general supervision of Dr. John Harrison, Chief, EL. Mr. J. Lewis Decell was Program Manager, APCRP. Mr. W. N. Rushing, APCRP, was responsible for planning and chairing the meeting.

COL Nelson P. Conover, CE, was Commander and Director of the WES at the time of this meeting and during the preparation of the proceedings report. Mr. F. R. Brown was Technical Director.

CONTENTS

-> Topics at this meeting included: Problem Identification and Assessment; Te[illegible] [illegible] [illegible] ->

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GENERAL STUDIES

BIOLOGICAL CONTROL; TECHNOLOGY DEVELOPMENT ;)

MECHANICAL CONTROL; TECHNOLOGY DEVELOPMENT

->and CHEMICAL CONTROL; TECHNOLOGY DEVELOPMENT

Large-Scale Operations Management Tests; and Aquatic Plant Control [illegible]

ATTENDEES

15th ANNUAL MEETING
U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL RESEARCH PROGRAM

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AGENDA

15th ANNUAL MEETING
U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL RESEARCH PLANNING
AND OPERATIONS REVIEW

Savannah, Georgia

17-20 November 1980

<u>Monday, 17 November 1980</u>

8:30 a.m. to 4:30 p.m.	Federal Aquatic Plant Management Working Group--Winged Foot Room
10:00 a.m. to 6:00 p.m.	Registration--Marine Directors Room
6:30 p.m.	Reception--Ballroom A

<u>Tuesday, 18 November 1980</u>

Ballrooms B and C

8:00 a.m.	Registration continues--Marine Directors Room
8:30 a.m.	Call to Order and Announcements - W. N. Rushing, Waterways Experiment Station (WES)
8:45 a.m.	Welcome to Savannah District and South Atlantic Division - LTC Walter Heme, Deputy District Engineer, USAE District, Savannah, GA
9:00 a.m.	General Comments - Mr. Gerald Purvis, Chief, Recreation Resources Management Branch (RRMB), Office, Chief of Engineers (OCE)
9:15 a.m.	Establishment of the APC Operations Support Center at the Jacksonville District - Mr. Dwight Quarles, RRMB, OCE*
9:30 a.m.	The APCRP from a Different Perspective - J. L. Decell, Manager, Aquatic Plant Control Research Program (APCRP), WES

* Presentation not submitted for inclusion in Proceedings.

9:45 a.m.	Break
10:15 a.m.	Industry Session - C. Hudson, Ortho Division, Chevron Chemical Company*
10:30 a.m.	W. Arnold, Lilly Research Laboratories, A Division of Eli Lilly and Company
10:45 a.m.	W. Moore, Pennwalt Corporation
11:00 a.m.	J. Gallagher, Union Carbide Agricultural Products Company
11:15 a.m.	D. Paschke, Applied Biochemists, Inc.
	D. Widmann, Nalco Chemical Company*
	A. Fuchs, Sandoz, Inc.
	B. Still, B. Still, Inc.*
11:30 a.m.	Other Industry Representatives and/or General Discussion
12:00 noon	Lunch
1:30 p.m.	USAE Division/District Presentations--Aquatic Plant Problems--Operations Activities
	Lower Mississippi Valley Division, Memphis District (Lake Wappapello) - R. Hite
	Missouri River Division, Omaha District - J. Anderson*
	North Central Division, St. Paul District - W. Koerner*
	North Pacific Division - O. Beckwith, Seattle District - R. Rawson
	South Atlantic Division, Jacksonville District - J. Joyce, Savannah District - J. Patti*
	Southwestern Division, Galveston District - L. Hunt, Tulsa District - P. Mace
3:15 p.m.	A Cooperative Agreement for Accomplishing an Aquatic Plant Control Program in Washington State - R. Pine, Washington Department of Ecology, Olympia, WA
3:30 p.m.	Break

* Presentation not submitted for inclusion in Proceedings.

4:00 p.m.	Problem Identification and Assessment - A. M. B. Rekas, WES, Presiding
4:05 p.m.	Techniques for Large Area Surveys of Aquatic Plants as Applied in Panama and Texas - S. D. Parris, WES
4:25 p.m.	Ground and Aerial Surveys of Giant Cutgrass in Lake Seminole, A Discussion of Techniques - J. M. Leonard, University of Idaho, Moscow, ID
4:45 p.m.	An Adaption of Existing Instrumentation Technology to Aquatic Plant Monitoring - A. M. B. Rekas, WES
5:00 p.m.	Adjourn for the Day

Wednesday, 19 November 1980

Ballrooms B and C

8:30 a.m.	General Studies - W. N. Rushing, Presiding
8:35 a.m.	Recording Fathometer for Hydrilla Distribution and Biomass Studies - J. V. Shireman, University of Florida, Gainesville, FL
8:55 a.m.	Laboratory Studies of Several Submersed Aquatic Plant Species - J. Barko, WES
9:15 a.m.	Evaluation of Mathematical Models for Use in the Aquatic Plant Control Research Program - J. Wlosinski, WES
9:35 a.m.	Break
10:00 a.m.	Biological Control Technology Development - D. R. Sanders, WES, Presiding
10:10 a.m.	Dispersal and Efficacy of *Sameodes albiguttalis* on Waterhyacinth in Florida - T. D. Center, USDA, Fort Lauderdale, FL
10:30 a.m.	Domestic Survey for Invertebrates on Eurasian Watermilfoil and Hydrilla - J. K. Balciunas, USDA, Fort Lauderdale, FL
10:50 a.m.	Evaluation of Insect Species for Biocontrol of Aquatic Plants - G. R. Buckingham, USDA, Gainesville, FL
11:30 a.m.	Quarantine Studies of *Fusarium roseum*, a Fungal Pathogen for Control of Hydrilla - R. Charudattan, University of Florida, Gainesville, FL

11:50 a.m.	Microbiological Control of Eurasian Watermilfoil - H. Gunner, University of Massachusetts, Amherst, MA
12:10 p.m.	Lunch
1:40 p.m.	Mechanical Control Technology Development - H. W. West, WES, Presiding
1:45 p.m.	Field Evaluation of the Limnos, Ltd., Mechanical Harvesting System for Control of Hydrilla - J. Smith, Colorado State University, Ft. Collins, CO
2:00 p.m.	Prediction of Equipment Performance for Optimal Harvesting of Submerged Aquatic Plants - T. D. Hutto, WES
2:15 p.m.	Effects of Water Disposal of Mechanically Processed (Chopped) Hydrilla - B. M. Sabol, WES
2:30 p.m.	Prediction of Hydrilla Growth and Biomass for Scheduling Mechanical Control Operations - D. Miller, WES
2:45 p.m.	Break
3:15 p.m.	Chemical Control Technology Development - H. E. Westerdahl, Presiding
3:20 p.m.	Development of Controlled Release Herbicide Technology Using Polymers - F. W. Harris, Wright State University, Dayton, OH
3:40 p.m.	Field Evaluation Objectives and Plans for Controlled Release Herbicides - R. E. Hoeppel, WES
4:00 p.m.	Screening Chemicals for Aquatic Plant Control - K. K. Steward, USDA, Fort Lauderdale, FL
4:20 p.m.	Identification of a Naturally Occurring Inhibitor for Hydrilla Control - D. F. Martin, University of South Florida, Tampa, FL
4:40 p.m.	New Controlled Release Chemical Formulations - C. Himel, University of Georgia, Athens, GA
5:00 p.m.	Adjourn for the Day

Thursday, 20 November 1980

Ballrooms B and C

LARGE-SCALE OPERATIONS MANAGEMENT TESTS (LSOMT)

8:00 a.m.	Use of White Amur for Control of Hydrilla in Lake Conway in the Jacksonville District - A. Miller, WES, Presiding
8:05 a.m.	Aquatic Macrophytes - J. Schardt, Florida Department of Natural Resources, Tallahassee, FL
8:20 a.m.	Fish, Mammals, and Waterfowl - R. Land, Florida Game and Fresh Water Fish Commission, Tallahassee, FL
8:35 a.m.	Water Quality - R. Kaleel, Orange County Pollution Control Department, Orlando, FL
8:50 a.m.	Benthos - T. C. Crisman, University of Florida, Gainesville, FL
9:05 a.m.	Herpetofauna - J. S. Godley, University of South Florida, Tampa, FL
9:20 a.m.	Radiotelemetry Tracking of White Amur - M. Keown WES
9:35 a.m.	Break
10:00 a.m.	Use of Prevention Methodology for Eurasian Watermilfoil Control in the Seattle District - A. M. B. Rekas, WES, Presiding
10:15 a.m.	Analysis of Monitoring Procedures and Milfoil Fragment Barrier Effectiveness - E. A. Dardeau, Jr., WES
10:30 a.m.	Eurasian Watermilfoil Treatment with 2,4-D, Diquat, and Endothall at Reduced Application Rates - K. J. Killgore, WES
10:45 a.m.	Physiologic Impact of Mechanical Harvesting Eurasian Watermilfoil - M. A. Perkins, University of Washington, Seattle, WA
11:00 a.m.	Use of Biological Agents for Control of Waterhyacinth in the New Orleans District - R. F. Theriot, WES, Presiding
11:15 a.m.	Mass Release of Arzama - A. F. Cofrancesco, University of Southern Mississippi, Hattiesburg, MS
11:30 a.m.	Large-Scale Field Application of *Cercospora rodmanii* - E. A. Theriot, WES

12:00 noon	Use of Aquatic Plant Control Technologies in the Panama Canal - W. N. Rushing, WES, Presiding
	Organisms Impacting Waterhyacinth in the Panama Canal Zone - D. R. Sanders, Sr., WES
12:15 p.m.	Evaluation of Aquathol K and Hydout for Hydrilla Control in Gatun Lake, Panama Canal Zone - H. E. Westerdahl, WES
12:30 p.m.	Final Wrap-Up and Adjournment - J. L. Decell
12:35 p.m.	Lunch
2:00 p.m. to 5:00 p.m.	FY 82 Civil Works R&D Program Review - R&D Office, OCE, St. Andrews Room (Corps representatives only)

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons (U. S. liquid)	3.785412	cubic decimetres
inches	25.4	millimetres
miles per hour (U. S. statute)	1.609347	kilometres per hour
miles (U. S. statute)	1.609347	kilometres
ounces (U. S. fluid)	29.57353	cubic centimetres
pounds (mass)	0.4535924	kilograms
pounds (mass) per acre	0.000112	kilograms per square metre
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square inches	645.16	square millimetres
tons (mass) per acre	0.22	kilograms per square metre
tons (2000 lb, mass)	907.1847	kilograms
yards	0.9144	metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use $K = (5/9)(F - 32) + 273.15$.

15TH ANNUAL MEETING

U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Introduction

As part of the Corps of Engineers (CE) Aquatic Plant Control Research Program (APCRP) it is required that a meeting be held each year to provide for professional presentation of current research projects and review current operations activities and problems. Subsequent to these presentations, the Civil Works Research and Development Program Review is held. This program review is attended by representatives of the Civil Works and Research and Development Directorates of the Office of the Chief of Engineers; the Program Manager, APCRP; and representatives of the operations elements of various Division and District Engineer Offices.

The overall objective of this annual meeting is to thoroughly review Corps aquatic plant control needs and establish priorities for future research, such that identified needs are satisfied in a timely manner.

The technical findings of each research effort conducted under the APCRP are reported to the Manager, APCRP, U. S. Army Engineer Waterways Experiment Station (WES), each year in the form of quarterly progress reports and a final technical report. Each technical report is given wide distribution as a means of transferring technology to the technical community. Technology transfer to the field operations elements is effected through the conduct of demonstration projects in various District Office problem areas and through publication of Instruction Reports (IR), Engineering Circulars (EC), and Engineering Manuals (EM). Periodically, results are presented through publication of an APCRP Information Exchange Bulletin which is distributed to both the field units and the general community. Public-oriented brochures, movies, and speaking engagements are used to keep the general public informed.

The printed proceedings of the annual meetings and program reviews are intended to provide Corps management with an annual summary to ensure that the research is being focused on the current operational needs on a nationwide scale.

The contents of this report include the presentations of the 15th Annual Meeting held in Savannah, Georgia, 17-20 November 1980.

PROCEEDINGS

RESEARCH PLANNING CONFERENCE ON THE AQUATIC PLANT CONTROL RESEARCH PROGRAM

The Recreation Resource Management Branch Responsibilities in Research and Aquatic Plant Control Program

by

Gerald Purvis*

The Recreation Resource Management Branch, of the Office, Chief of Engineers, U. S. Army, has overall staff supervision of the Aquatic Plant Control Research Program. We also serve as technical monitors of the associated research efforts. As many of you also know, a few changes have been made in our branch in the last year or so. I became the Branch Chief just prior to your last annual meeting and Roger Hamilton who has been the technical monitor has temporarily gone on to greener pastures as a Planning Associate for a year. While Roger is gone, Dwight Quarles is serving in his place as Section Chief and Tech Monitor for aquatic research.

We realize, therefore, that our in-depth knowledge of the progress made in aquatic plant control is lacking. So, I'm looking forward to this meeting to not only identify and offer solutions to programmatic problems but as a learning experience for myself.

In reviewing the operations and research efforts concerned with aquatic plant control, I have been impressed with the dedication and professionalism of the personnel involved. I see a program that in my opinion has been turned into a viable, progressive Corps mission in the past few years and I see no reason why this objective management will not continue in the years ahead.

For those of you that aren't familiar with the Recreation Resource Management mission, I would like to give you a very brief overview. In our data system we list 449 water resource development projects that have a visitation of more than 5000 annually. We experienced a visitation in 1979 of over 426 million. The Corps has under it's management responsibility 5 million acres** of water, 6 million acres of land, 22,000 miles

* Chief, Recreation Research Management Branch, Office, Chief of Engineers, U. S. Army, Washington, D. C.

** A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 23.

of inland waterways, 3,000 miles of intercoastal waterways, and over 400 small boat harbors.

In a recent discussion with the Director of Civil Works, I discussed the pressing issues of our mission in the 1980's. He listed among his top priorities the protection, management, and enhancement of the natural resources of our projects. He particularly emphasized our role as custodians of the nation's water resources. I feel very strongly that our emphasis in the 1980's will be the resource portion of our function.

I believe you and I face unique challenges in aquatic plant control in the 1980's. We most certainly will face a shrinking dollar while every indication leads to the inescapable conclusion that the problems of aquatic plant control are on the verge of significant increases in areas of the country where we have previously experienced little trouble. We must continue through research to plan and implement more efficient methods of management and operations and we must ensure that transfer of that technology is made to others.

During the aquatic plant control meeting at Lake Eufaula, Oklahoma, in November 1979, Roger Hamilton passed out a questionnaire designed to gauge the attendees' perceptions of our overall research, planning, and control efforts. I believe it's important that you be aware of the perceptions indicated by the respondents to that survey.

A total of 106 people returned a completed questionnaire. Of these, almost exactly half were Corps of Engineer employees, and the remainder were fairly evenly distributed among local and State agencies, private endeavors, and the academic community. Researchers, planners, and policy/administrators greatly outnumbered the people working in control operations.

Slightly less than one third of the respondents felt that our current legislation provides an adequate base for the aquatic plant program. The remaining two thirds either felt that our legislation was inadequate, or they were not familiar with the legislation. The "unfamiliar" category was the most disquietening because it alone accounted for one half of all respondents.

The perceptions of Corps policy and management were certainly much clearer than for legislation. Almost 95 percent of the respondents indicating a knowledge of Corps policy said it was adequate to govern the program, and 97 percent felt that management was good or excellent. Only 3 percent of the respondents felt that both policy and management were inadequate. There was overwhelming support that a Center of Competence (or an Aquatic Plant Control Support Center) was needed. OCE has concurred in that need and Dwight Quarles will detail to you the perimeters and conditions that have been determined for implementing the establishment of the support center in the Jacksonville District.

Last year's group indicated overwhelming support for the Large-Scale Operations Management Test (LSOMT). Their responses indicated that they were firmly convinced that:

a. LSOMT is an effective method of technology transfer.

b. The Corps is very effective in identifying areas that lend themselves to this type of technology transfer.

c. Almost 85 percent stated that they, or their organization, had benefited from these tests. Some 90 percent also rated the technology transfer aspects of the overall aquatic plant control program as either adequate or excellent.

I believe the establishment of the Aquatic Plant Control Center will further facilitate this technological transfer.

Almost three fourths of the respondents indicated frequent receipt of research publications. The same approximate percentage indicated that they read more than half the publications; however, a significantly smaller group found the publications useful in their work.

As one of the television networks said about another recent poll, "Our survey really wasn't scientific, it doesn't lend itself to statistical analysis, its results probably only reflected what the respondent was thinking at the time, and it might not accurately reflect their later actions."

While I realize that this modest effort at judging the users' perceptions of the Corps' efforts has its limitations, it does appear to reflect a collective judgment that the Corps can identify an area needing work, look into it, and get the results to the users in an understandable and usable form.

The Huntsville Division recently sent out a questionnaire asking about the need for formal training in aquatic plant control. We have reviewed the results of that survey and are convinced that the 35 to 40 respondents really are in the direct planning and control elements concerned with aquatic plant control.

We feel we don't have sufficient information to implement a formal training course at this time. We also think any urgent training needs can be met through our existing, technological transfer system, informal workshops, this meeting, and the Aquatic Plant Control Support Center.

If anyone has any questions or problems they wish to ask concerning this area, they should by all means do so during this meeting, either to Dwight Quarles or myself.

Certainly through surveys such as these and the results of this meeting we can determine the trends developing in the aquatic plant control program and the directions we should be taking to effectively manage our program.

INDUSTRY SESSION

Lilly-Elanco

by

W. Arnold*

I want to take this opportunity to express my appreciation for this invitation to discuss Lilly Research Laboratories perspective of the Corps' program and aquatic plant control.

The questions:

a. How does Lilly-Elanco perceive their interaction with the Corps' Aquatic Plant Control Research Program?

We see the Corps as being a very vital sector in the research and development phase of new products as well as in the marketplace. The vital sector in the development phase would be the location and application of test sites, designing protocols on specific areas of need, and implementing those protocols in cooperation with the technology developed by our company. We see the technology developed by our company as being shared with the Corps of Engineers.

We envision some date in which the Corps may decide to apply for Experimental Use Permits for certain aquatic problems.

b. How can the Corps do a better job from our standpoint?

We would like to become better acquainted with your people involved in aquatic programs and aquatic problems. This meeting is an excellent atmosphere for becoming better acquainted; however, we need to know what industry can supply to meet the problems and challenges in aquatics. Lilly's commitment to scientific research is 70 years old, and no one in Lilly can envision any circumstances that would cause us to change that commitment. We at Lilly are constantly adopting innovative concepts to attack new and increasingly complex research objectives, but we need to identify and define needs in the aquatic environment.

c. How do you view the future for development in your area of interest and in aquatic plant control as a market?

Lilly-Elanco views the aquatic market as a long-term commitment. We intend to be a multiproduct company with scientific research of the highest order, directed toward major marketplace needs. We feel that the general public doesn't perceive water as a natural resource such as oil, but in certain portions of the world the quality of water is of the utmost concern. We hope, as a company, to integrate our products into controlling factors that can enhance the availability of good quality water.

* Lilly Research Laboratories, a Division of Eli Lilly and Company, Florida Research Station, Boynton Beach, Florida.

We have conducted research in the areas of aquatic growth regulators, algicides, and herbicides. We feel that the Corps of Engineers is on the cutting edge of knowing our water resources needs and we look to you to tell us the direction of research programs before a potential crisis occurs.

INDUSTRY SESSION

Pennwalt Corporation

by

W. Moore*

The Corps' Aquatic Plant Control Research Program is very meaningful to Pennwalt for the following reasons:

a. There is a direct relationship between Corps funding for aquatic weed control and our sales of aquatic herbicides.

b. Testing and data collection performed by the Corps with our herbicides help us to keep and expand our aquatic herbicide labels. New labels currently pending with the Environmental Protection Agency (EPA), if approved, should greatly expand the use of endothall herbicides. Many basic questions concerning the effect on water quality, method of application, and use of additives can be answered with your help.

Pennwalt has no new aquatic herbicides under development at this time. We are continuing to investigate the use of new technology with endothall in the following areas:

a. Other endothall formulations.

b. Slow release formulations.

c. Dust-free pellets and granules.

d. The use of additives such as polymers, inverts, and surfactants.

e. Combinations with other herbicides.

The market for herbicides for submerged aquatic weed control is not as large as many people conceive. It is especially small when compared to the agricultural herbicide market. However, Pennwalt is committed to the aquatic weed control market. We have established a separate Aquatic Chemical Department within the Agricultural Chemical Division of our company. This will allow us to provide more specialization and expertise to better service the market.

We at Pennwalt are trying to do a good job of providing information and educational materials on our products to those who are involved in aquatic weed control. Pennwalt aquatic chemicals play an important role in the control of noxious aquatic weeds and algae without harm to the environment. The use of our herbicides is also cost-effective when compared to other methods of aquatic weed control. We want the correct story to be told.

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* Pennwalt Corporation, Winter Garden, Florida.

INDUSTRY SESSION

Union Carbide Agricultural Products Company, Inc.

by

John E. Gallagher*

To answer the questions raised by Mr. Decell, I will use an outline to suggest policy, research needs, and problem areas which might be addressed by the Corps. Many of the areas touched upon could be the basis for much longer discussions.

I. The Uniqueness of Aquatic Weed Control. Aquatic weed control is categorized as a minor use segment of weed science, yet the problem is widespread, not regional, since aquatic weed problems are critical in all parts of the world. The problem is further confounded by:

   A. Diversity of Pest Species

      1. Native species - usually having an established niche.

      2. Introduced species - having the capability of an explosive rate of spread due to a lack of natural predators.

   B. Environment Modifications

      1. Actions that modify or affect the stability of an aquatic ecosystem generally aid and abet the spread of problem species.

      2. Use patterns, particularly those that stress the natural community competitiveness, tend to determine species dominance.

II. Industry - Corps or Other Federal Agency Interaction

   A. Concept of agency purchaser and applicator - its limitations. Historically, the Corps and Department of Interior (Bureau of Water and Power) out of necessity had to research and develop application methodology. Times and values have forced changes.

      1. The establishment of EPA (a necessary agency).

      2. The gradual decline of available herbicides.

      3. The industry prioritization of development cost which places aquatic herbicide use on a low priority.

   B. Old methods are not applicable to today's needs and the following action should be considered:

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* Union Carbide Agricultural Products Company, Inc., Ambler, Pennsylvania.

1. Establish the state of the art. Update what is known.

2. Maximize information transfer to the field.

3. Initiate needed research programs either in-house or fund cooperatively.

4. Remove the word eradicate from administrative language.

5. Encourage industry to continue research efforts in the aquatic field.

C. Interact with EPA. Begin to establish an organized policy toward EPA and other critical regulatory agencies.

1. Establish an in-house department of specialists to aid in label registration.

2. Organize and coordinate Experimental Use Permits programs alone and in cooperation with IR-4 groups.

D. Needed Corps Cooperative Actions

1. Act as a lead agency in research and the funding of research in total aquatic plant management programs.

   a. Support screening programs.

   b. Support small plot field tests.

   c. Support large-scale Experimental Use Permits projects.

      (1) Cost share control agent.

      (2) Provide site and operation personnel.

      (3) Maintain test sites.

2. Coordinate operational programs with other Integrated Pest Management projects to evaluate whole watershed systems. Corps controlled watershed management programs should be coordinated to provide total impact data packages.

   a. Collect long-term data.

   b. Build a case history of successful aquatic plant management programs to be able to more forcibly counteract opposition.

3. Take positive action.

   a. Become an activist agency in terms of risk/benefit or cost/benefit ratios when dealing with aquatic plant management programs.

   b. Blow your own horn - let more people know of the good that is accomplished.

   c. Support your industry cooperators by allowing your research specialist group to override your purchasing agent.

III. The Future

A. Market Activity in Aquatic Weed Control - Short Term

1. A slow growth industry frustrated by over-regulation which will support a limited number of participants.

B. Long Term

1. A worldwide commodity need, but not an easy market to maintain even in the face of limited water supplies.

2. In the final sense, continued development of aquatic herbicides has to be a cooperative effort between industry and the Corps. A partnership of sorts that is directed toward providing the most efficacious and minimum risk combination of pest plant management.

INDUSTRY SESSION

Applied Biochemists, Inc.

by

Dave Paschke* and Jim Schmidt*

As a small company involved in the aquatic pest control industry, Applied Biochemists, Inc., views the Corps' activities in this field both as a viable market for our products as well as a means of testing material for label expansion. We appeal to the Corps to give cutrine-plus consideration in both testing and operational programs. Within our means, we are willing to participate in research activities. Use of cutrine-plus in tank mix combinations with registered herbicides, in conjunction with polymers, and by itself warrants further examination against certain target pests. Our present label would allow for much of the work to be conducted without registration problems.

We suggest that the Corps establish a timely industry notification system whereby we are notified in advance of product testing and application sites. Emphasis should be placed on working with presently registered or potentially registerable materials. Greater efforts should be made toward informing the public of the environmental and human safety considerations which have been made in choosing chemical control techniques. The future of aquatic pest control will trend towards integrated methodology. Chemicals will be a continuing necessity from a cost-effective standpoint. As a manufacturer, we are seeking closer involvement with Corps personnel and activities in the future.

* Applied Biochemists, Inc., Mequon, Wisconsin.

INDUSTRY SESSION

Sandoz, Inc.

by

A. F. Fuchs, Jr.*

For those who aren't familiar with Sandoz, Inc., let me briefly give you some background information. Sandoz, Inc., is the subsidiary of Sandoz, Ltd., Basle, Switzerland. Founded in 1886, our parent company is one of the 200 largest industrial firms based outside of the United States, with 35,000 employees and operations in 42 countries. The products of Sandoz include pharmaceuticals, chemicals, dyestuffs, specialty foods, seeds, and agrochemicals. Worldwide sales by Sandoz are close to \$2.8 billion. Sandoz spent approximately \$3 million this year (1980) on agrochemical research in the United States.

Sandoz has two products that are presently used in various areas of the United States to control plant growth:

- a. Komeen (aquatic herbicide) is an ethylenediamine chelated copper used to control hydrilla, Brazilian elodia, and southern naiad.
- b. K-Lox (algicide) is a triethanolamine chelated copper used to control various algae.

These products play an important role in the Corps' aquatic plant control program.

How can the Corps do a better job from my standpoint? In accordance with the Endangered Species Act of 1973, as amended in 1978, Federal Agencies must ensure that their actions do not threaten the continued existence of endangered species. The continued existence of chemicals for aquatic plant control is endangered and we <u>must</u> be concerned about the power of this act. I would like to see the Corps of Engineers take a <u>leadership role</u> to include industry in consultation concerning an endangered species when the "stop use" of a particular product is involved. All industry is very concerned about endangered species, especially Sandoz. But sometimes decisions are made to stop the use of certain products, when possibly after hearing industries views, the product could continue to be used while testing is being conducted. Industry should be included in the test program because of its specific knowledge of its products. Hastily banning the use of an aquatic herbicide could have serious long-term consequences. Some people will continue to consider the product "unsafe" even after <u>proven</u> safe. It is like the judge who tells the jury to disregard what was said, but we all know that every person on the jury will remember what was said.

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Give industry the benefit of the doubt so it doesn't lose sales and profits. These are needed to develop new aquatic products and pay taxes that are used to fund various Federal and State aquatic programs. Don't take away the incentives for industry to expand in the aquatic field. Please bear in mind that I am referring to situations where there is only speculative information that a particular product is affecting an endangered species. This is all that is needed under the present Endangered Species Act to overrule years of testing and spending, sometimes millions of dollars to register a product with EPA and/or a state.

How do I view the future for development in the aquatic herbicide field? The future of chemicals for aquatic plant control depends on how regulated industry will be and how much funding is available to Federal and State agencies for aquatic weed control. Industry must have an incentive for management to justify expenditures to develop and register a product for aquatic plant control. Fortunately, or maybe I should say, unfortunately, the world population is now about 4 billion and will double in the next 35 years to 8 billion. This means that we must double food production in the next 35 years just to feed people at today's level (which doesn't include everyone). Due to this situation, Sandoz research is continually trying to develop new chemicals to help increase crop production and, hopefully, some of these products will be used in the aquatic industry. Sandoz is a world leader in biochemical research and development. This may be the answer for the future.

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

Lower Mississippi Valley Division, Memphis District (Lake Wappapello)

by

Richard L. Hite*

For several years Lake Wappapello has been plagued with a significant infestation of *Najas minor* (brittle naiad), which grows virtually unchecked throughout most of the lake. As a result, we receive numerous complaints from boaters, fishermen, skiers, and swimmers.

Lake Wappapello, which is in the Memphis District, is a relatively old (1941) and shallow lake. The average depth at summer pool, 360 ft mean sea level (msl), is only 12 ft. The lake has a great number of springs. This, and the rocky, graveled creek bottoms contribute to the lake's good water quality. Where aquatic vegetation is not present, the lake and tributaries are quite clear.

Water is routinely sampled and tested from six different locations and levels from surface to 11 m depending on location and present lake level. These parameters include: temperature, dissolved oxygen, total coliform, conductance, and pH. The tests have never indicated any type of pollution. However, we wonder about the possibility of excessive fertility resulting from sewage, agricultural fertilizer, cattle lots, etc.

The University of Missouri sampled the lake vegetation in July 1978 and reported that naiad comprised 99 percent of the total vegetation. Other species included pondweed, duckweed, and milfoil. It is also significant that Lake Wappapello is the only major impoundment in Missouri that contains brittle naiad. This is probably due to the warm shallow water conditions at Wappapello. We have not had any formal research conducted. However, we have observed increased growth of the species during hot, dry summers such as this past summer (1980) when summer surface temperatures averaged 28°C.

Past and present control methods have been costly and futile. For the past 6 years during April and June we have sprayed Aqua-Kleen (2,4-D), a product of the Amchem Corporation, at 200 lb/acre around intensive-use areas. However, we don't feel that the chemical is effective. This is more of a cosmetic exercise to appease dock operators and the general public.

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* U. S. Army Engineer Division, Lower Mississippi Valley; Memphis District, Memphis, Tennessee.

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USAE DIVISION/DISTRICT PRESENTATIONS

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USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

New England Division*

by

Irving Fistel**

The Aquatic Plant Control Research Program, as presently authorized and administered, has significant gaps that in New England, and probably in other areas of the country, prevent us from effectively combating the agents that cause the development of aquatic plant problems. Inadequacy is not related to the intent of the program but to the scope and objectives we are limited to.

It is apparent from our experience in administering this program in New England that the majority of aquatic plant problems we deal with are intimately related to the type and degree of development common to our area. The root sources of most of our problems are the changes man has engendered in the watersheds because of his immediate presence and activities. By concentrating people around our lakes and waterways, we have tremendously increased the rate at which these resources age. The agents that enhance the aging process are the nutrients that are literally flushed into the waters from the homes, businesses, and recreation areas surrounding them. In our authorized attempts to control obnoxious aquatic plant growth, we are in a sense combating the obvious effect of these activities while avoiding the causes.

Nearly every aquatic plant control problem we have seen would be technically defined as a condition of advanced eutrophication or enrichment, which is the natural phenomenon that ages water bodies. The result of our presence is that the total amount of nutrients available for plant growth is tremendously increased. Aquatic plants respond to this increased amount of material by greatly enhanced growth. This growth is often reflected in the size of plants as well as the numbers of individual plants. Our priorities are in need of revision. True, we generally become involved after prevention is no longer possible, but a prime requirement of permanent control is limiting continuation of fertility. In the terms of our existing technology, we are severely limited in methods of controlling the enrichment of our most urbanized water resources.

We are about to propose a year-long study of a culturally impacted lake, Fort Meadow, in Marlboro, Massachusetts, to develop a program to

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* This paper was not presented at the 15th Annual Meeting but is included here for information purposes.

** U. S. Army Engineer Division, New England; Waltham, Massachusetts.

control present aquatic growth and prevent further degradation of water quality. The results of this study, if approved by OCE, would give guidance to a long-term effort to correct the problem. Our first step would be submission of the scope to OCE with a proposed funding level. Concurrence of OCE and funding provided by them would be utilized by the New England Divison to initiate the fieldwork next spring. Fieldwork would involve water quality, lake sediment, plant identification, and other biological sampling to determine the sources and extent of eutrophication of the Fort Meadow Reservoir, built over 100 years ago for industrial water storage. The study will also identify the point sources of enrichment in the basin and relate them to the development of the aquatic plant problem. We will also look into the flow dynamics of the system to see if a hydrologic management schedule can be imposed to help alleviate some of the problems. Once we can identify the type and amount of enrichment and the potential for management we will be able to formulate a program that will utilize conventional aquatic plant treatment with necessary elimination of nutrients by treatment or diversion to prevent some of the water quality degradation. The key word is prevent. If we can gear our program to the preventative rather than the curative, we hope to be able to reclaim, at least to some degree, our most abused water resources. We will also be in a position to implement environmental controls for our remaining high quality water resources.

In summary, we find that in New England local people are alarmed and confused by the appearance of an aquatic weed problem. They do not comprehend the reason for subtle developments and often will not accept the fact that the control procedures they have used for many years have proven to be inappropriate and that their cumulative effect is the objectionable growth. Generally, the people are becoming educated to the reasons for these problems. Since local funding and expertise are limited, they seek assistance through applicable Federal and State programs. We are hopeful that the next few years will show if the Corps' program will be of help to New England's aquatic weed problems.

USAE DIVISION/DISTRICT PRESENTATIONS
AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

North Pacific Division

by

Orrin Beckwith*

The Aquatic Plant Control Research Program in the North Pacific Division is concentrated on one plant, Eurasian watermilfoil, and major efforts to prevent and control this plant are centered in the State of Washington.

Since the 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 1979, we have added the State of Oregon as an entrant into the program. We were contacted in May 1980 by representatives of Oregon's Marine Board concerning problems in Blue Lake, Sturgeon Lake, and Smith-Bybee Lake, Multnomah County, Oregon. Eurasian watermilfoil has been positively identified in Blue Lake, although the other two lakes may require further verification. Our initial meeting with the State of Oregon involved the Division, Portland District, Oregon Marine Board, and Oregon Department of Agriculture. The program was explained, including discussion of potential problems, i.e., funding, use of chemicals, public opposition, etc., but still received positive reaction from the State. With a letter of intent from the State, we requested funds to accomplish the reconnaissance report. Since we were out of step with the budget cycle, funding was delayed until this fiscal year.

The Portland District has requested funding to initiate a Design Memorandum (DM) and Environmental Impact Statement (EIS) in FY 1982. The Portland District will proceed on the DM and EIS if the results of the reconnaissance study indicate that we should.

The basic problem is the lack of authority to enter into a preventative program with the northwestern states when we have not positively identified a problem. As it stands, by the time the Corps is informed that there is a problem, we know it will be 3 to 4 years before we have completed our studies and received our funding. By that time, the specific plant, in this case Eurasian watermilfoil, has usually become entrenched, requiring control or eradication measures rather than preventative measures.

* U. S. Army Engineer Division, North Pacific; Portland, Oregon.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

North Pacific Division, Seattle District

by

Robert M. Rawson*

The Seattle District has been involved in aquatic plant control only since 1977, when the Washington State Department of Ecology requested that a State-wide management plan for Eurasian watermilfoil be established. At that time, milfoil had been identified as the species causing problems and numerous complaints in the Seattle area. Around that same time, we became aware of serious problems in the Okanogan Lake Chain in British Columbia with milfoil moving rapidly downstream into Osoyoos Lake. A problem level population was also identified in Banks Lake, a Water and Power Resources Services reservoir in the Columbia Basin.

We had no in-house expertise in aquatic plant control at that time, so we asked WES for assistance. They assisted in getting our planning study started and developed a 3-year research program designed to evaluate control methods for adaptation to a prevention program.

We also received help from other organizations involved in aquatic plant control: the Jacksonville District, The Tennessee Valley Authority, and the British Columbia Ministry of the Environment, in particular.

With this help, we were able to complete our planning study in June 1980. We signed a cooperative agreement with the Washington State Department of Ecology, the State-wide sponsor, in July.

Because of the wide range of public concerns expressed during our planning process, we realized that no single control method would solve all of our problems. With this in mind, we geared our program, which requires 30 percent local matching funds, to be as flexible as possible. The local sponsor is left to choose the control method, within the framework of our program, which best meets local needs.

The first year's operation of our program consisted of mechanical harvesting and the use of fiberglass-bottom screens in high-use public recreation and navigation areas in Lakes Washington and Sammamish, in the Seattle area; the maintenance of a fragment barrier on the Okanogan River and spot treatments of the herbicide 2,4-D in Osoyoos Lake to prevent downstream spread; and the continuation of a public information program to minimize fragment spread by recreational boaters. These programs are expected to continue next year (1981).

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* U. S. Army Engineer Division, North Pacific; Seattle District, Seattle, Washington.

The top priority of our program is to keep milfoil from becoming established in the Columbia River. The Department of Ecology, in cooperation with Okanogan County, has conducted a holding action on the Okanogan River since 1977. This year, that work was incorporated into our cost-share program. The downstream spread of milfoil has been slowed, but not stopped. This summer, the WES field team found scattered milfoil plants down to the mouth of the river. Now that our operational program has been established, we can hopefully stop this spread.

The Department of Ecology has also confirmed milfoil in the Pend Oreille River, as far downstream as Boundary Dam. This is about 14 river miles from the confluence with the Columbia River.

In addition to these two tributaries, we have a potential fragment source at Banks Lake. This irrigation reservoir is filled by pumping water from the Columbia River and now contains several hundred acres of milfoil. The problem we face here is the fact that two of the pumps used to fill the lake are reversible. In times of high lake level and high power demand, the flow could be reversed for generation. This would result in water from the lake, possibly containing milfoil fragments, going back into the Columbia River.

In summary, we have the Columbia River threatened by the direct flow of fragments from two tributaries, from the possible two-way flow from an infested man-made lake, and from private boaters traveling from infested waters carrying fragments on their props or trailers. It's going to be a big job and this coming year is going to be a critical time for the Seattle District.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

South Atlantic Division, Jacksonville District

by

Joseph C. Joyce* and James T. McGehee*

The Jacksonville District's aquatic plant management program consists of the Cooperative Aquatic Plant Control Program, the Removal of Aquatic Growths Project, and operations conducted under specific project operations and maintenance authorities. During the period between FY 1969 and FY 1979, the overall program underwent an expansion in both scope and magnitude. The impetus for this expansion was (1) the introduction of new problem aquatic plant species, such as hydrilla; (2) the requirement for additional control methods to manage the new problem species and the diverse environmental situations associated with these problems; (3) a change in aquatic plant management philosophy to a maintenance control approach; and (4) the passage of various regulatory laws which require additional program assessment and coordination. The purpose of this paper is to briefly discuss the magnitude and direction of this expansion. Table 1 summarizes the areas of the program which have undergone the greatest expansion.

Operational Function Expansion

In FY 1969 the waterhyacinth was the only nuisance aquatic plant species covered under the program and the basic control method was the application of 2,4-D. By the end of FY 1979, the control program included 19 different plant species and integrated the use of chemical, biological, mechanical, and environmental manipulation techniques.

This expansion was necessitated by the spread of additional major problem species such as hydrilla and the initiation of a control program for minor problem aquatic plant species. This latter program was implemented due to the realization that, although infestations of these plants are generally localized, they can significantly interfere with water-related activities when they arise in critical locations. The treatment or clearing of a small access trail through these areas will often open a pathway to a relatively large area providing a substantial increase in the area available to the public. Also, the treatment of a major problem plant such as waterhyacinth or hydrilla opens a water area to habitation

* U. S. Army Engineer Division, South Atlantic; Jacksonville District, Jacksonville, Florida.

by other species which were not previously included in the program. If these plants are allowed to proliferate in previously cleared areas, a portion of the benefits derived from the initial treatment would be negated.

This increase in nuisance species and advancements in herbicide technology resulted in an increase in the number of herbicide formulations and application techniques under the District program. Currently, 10 different formulations of herbicides are employed, and application techniques include aerial and ground application of liquid and/or polymer formulations; surface or subsurface injection of liquid, polymer, or invert formulations; and surface application of herbicide pellets. Additionally, mechanical and biological control programs have been expanded to fully operational levels within fiscal and environmental limitations.

In keeping with Federal and Corps personnel ceilings and the emphasis on contracting of additional services rather than performance with Federal forces, Corps-hired labor operations have not significantly increased over this 11-year period. However, the number of contracts for support services has increased from 4 in FY 1969 to 32 in FY 1979. A majority of the additional control work has been performed by the State of Florida Department of Natural Resources under a cooperative cost-sharing contract. The State has further subcontracted this work to several tiers of local and regional agencies and private firms. This approach has placed the management of aquatic plants at the local governmental level, which is generally more familiar with the local aquatic plant problems and more responsive to the specific management needs.

Planning Function Expansion

The increase in the number of problem plant species and environmental awareness of the general public has also increased the expenditure for program management, planning functions, research and development efforts, and special projects. Numerous Federal laws have significantly increased requirements for program assessment, justification, and coordination. Examples of such laws include: the National Environmental Policy Act of 1969 (NEPA); the Federal Environmental Pesticide Control Act of 1972 (FEPCA); the Endangered Species Act; and the Resource Conservation and Recovery Act of 1976. As a result of these acts: (1) three Environmental Impact Statements and numerous environmental assessments have been prepared according to NEPA; (2) key personnel have been trained and certified as pesticide applicators for several categories in accordance with FEPCA; and (3) most recently the District has become involved in a Section 7 consultation with the U. S. Fish and Wildlife concerning potential impacts on the endangered species, the West Indian manatee (*Trichechus manatus*).

Throughout this program expansion, the Jacksonville District work force has remained relatively constant while the work load, complexity, and responsibilities have increased significantly. As noted in Table 1,

there has only been an increase of 2.5 man-years in the total District aquatic plant control work force. Two of these are allocated to the field offices to assist in the contract inspection and compliance function. The other 0.5 man-year is allocated to the District office for overall program management.

Funding

The net result of the program expansion discussed above has been an almost elevenfold increase in annual expenditures from approximately $514,000 in FY 1969 to approximately $5.75 million in FY 1979. These values represent the combined expenditure of the Corps and the State of Florida under the cooperative program.

Future of the Program

The direction which the program has taken is expected to continue. As current problem areas are brought under maintenance control, which reduces the overall costs of control, additional problem areas can be included under the program. This will allow the attainment of a greater amount of benefits under the program with the same level of expenditure. Pending a change in Federal policy, there will also be an increase in the amount of operations and services that are contracted out rather than performed with in-house personnel.

Perhaps one of the most challenging and potentially beneficial expansions in the Jacksonville District's program is the establishment of a Corps-wide Aquatic Plant Control Operations Support Center at the Jacksonville District. As reported at this conference by Mr. Dwight Quarles of the Chief of Engineer's Office, the Center was established to provide technical assistance to other Corps Districts on matters pertaining to aquatic plant control operations. Upon request, the aquatic plant control personnel in the Jacksonville District will assist other field operating units in the establishment of operational programs and provide technical guidance during the planning phases of aquatic plant control programs and other operational related matters. Since aquatic plant control is of such a specialized nature, assistance by the Center's personnel will allow other Districts to avoid some of the pitfalls associated with the establishment of a new program and to effectively manage nuisance aquatic plant infestations.

Table 1

Areas of Expansion in the Jacksonville District

Aquatic Plant Control Program

FY 1969 - FY 1979

	FY 1969	FY 1979
Expenditures	$514,000	$5.75 million
No. of Plant Species	1	19
Contracts and Government Agreements		
State	1	1
Subcontracts	1	21
Private firms		
Materials and equipment	2	7
Control work	0	2
Architect Engineer	0	1
Government agency agreements	0	4
Laws for Assessment and Coordination	1	4
Coordination with other Government agencies		
Federal	1	3
State	1	5
Assistance to other Districts/Agencies	0	6
Control Methods		
Mechanical systems	0	2
Biological agents	1	8
Chemical formulations	1	10
Manpower allocation (man-years)		
Corps		
District	2	2.5
Area Offices	21	23
State and Subs.	43	158*
District Office Manpower Allocation and Grade Structures		
Engineer	1	0
Biologist	0	1.5
Engineering Technician	1	1
Secretary	1 shared	1 shared
Clerk	1 shared	0

* Does not include part-time administrative and support personnel.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

Southwestern Division, Galveston District

by

Lee W. Hunt*

Status of the Aquatic Plant Control Program in Texas

The Galveston District administers an active aquatic plant control program in the State of Texas.

This program is a cooperative cost-sharing and contractual agreement between the Federal Government and local interests. The Galveston District represents the Federal Government, and the Texas Parks and Wildlife Department represents the State of Texas as the local cooperating agency. Field operations are carried out by the Texas Parks and Wildlife Department under the supervision of Mr. Lou Guerra, Director, Noxious Vegetation Control Program for the State of Texas.

Control activities are performed in 18 designated work areas in accordance with established priorities. These areas are oriented to the watersheds of major river basins and coastal drainage systems. Our program is primarily limited to activities in the lower portions of the following 10 work areas:

a. Nueces River Basin.

b. Guadalupe River Basin.

c. North Coastal Area.

d. Sabine River Basin.

e. Trinity River Basin.

f. Neches River Basin.

g. Cypress Creek Basin.

h. South Coastal Area.

i. San Jacinto River Basin.

j. Rio Grande Basin.

Primary activities currently consist of control of waterhyacinth and alligatorweed in southern and southeastern Texas. Most of this work is performed within 100 miles of the Texas coast.

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* U. S. Army Engineer Division, Southwestern; Galveston District, Galveston, Texas.

Waterhyacinth

Although we consider waterhyacinth to be basically under control, it continues to be a serious aquatic plant pest in Texas. Waterhyacinth infestations are presently most critical in the North Coastal Area and Sabine River Basin. The San Jacinto, Trinity, Guadalupe, and Nueces River Basins are also problem areas that require frequent herbicide treatment. Control measures for waterhyacinth involve the use of EPA-approved formulations of 2,4-D.

Alligatorweed

Infestations of alligatorweed have increased in recent years throughout much of southeast Texas. The estimated acreage of alligatorweed occurring in Texas for 1971 to May 1979 has increased from 8,400 acres in 1971 to approximately 11,400 acres at present. The Trinity and Sabine River Basins and North Coastal Area are the most critically infested regions at this time. However, extensive infestations also occur in the Neches and San Jacinto River Basins.

Alligatorweed control methods to date have involved the use of the *Agasicles* flea beetles (*Agasicles hygrophilla*). Although flea beetles have been introduced at selected localities in five Texas work areas since 1967, their weed destruction capabilities have met with limited success. No releases have been made since 1974 as part of the Texas Aquatic Plant Control Program.

Hydrilla

Hydrilla (*Hydrilla verticillata*) has become a serious problem in portions of Texas; however, control of this species is not presently authorized as part of the Galveston District's Aquatic Plant Control Program. Hydrilla was first discovered in Texas in 1970 in the reflection pool of the Houston Zoo. Infestations have continued to increase substantially in portions of Texas with approximately 8,000 acres of hydrilla reported in Texas in 1979. The most serious problem presently occurs in Lake Conroe in the San Jacinto River Basin, where 32 percent of the 21,000-acre lake is infested. In order to include hydrilla in our control program, economic and environmental studies are presently being conducted in order to revise the General Design Memorandum and supplement the Environmental Impact Statement to include control of this species. Treatment to date in Texas has primarily involved experimental control on Lake Conroe and Lake Livingston by the Texas Parks and Wildlife Department.

Problems and Needs

During our studies to revise the General Design Memorandum and Environmental Impact Statement, we found that much of our information was insufficient to determine the effectiveness of our present program. A comprehensive survey of the extent of aquatic weed infestations in the Galveston District has not been conducted since 1971. A resurvey is needed in order to document the spread of certain species and to develop a data base to measure the effectiveness of our control program.

In April 1980, the Galveston District and the Southwestern Division (SWD) contacted the WES for assistance with our Aquatic Plant Control Program. We determined in coordination with SWD and WES that this was an excellent opportunity to use the expertise and services of WES personnel to help develop a comprehensive management plan for aquatic plant control. Our request was twofold: first to utilize rapid survey methods developed by WES to update our aquatic plant survey, and second to develop a plan for establishment of biocontrol agents in Texas on waterhyacinth and alligatorweed.

An agreement was developed with WES and cooperative work was started in FY 1980 and will continue until completed. We feel that this cooperative program with WES will greatly increase the capability of the Galveston District in development of better methods of aquatic plant control in Texas.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

Southwestern Division, Tulsa District

by

J. P. Mace*

Tulsa District is involved in the Aquatic Plant Control Research Program (APCRP) not because we have the overwhelming problems experienced by the southeastern states, but because we have the potential for those problems. Eurasian watermilfoil (*Myriophyllum spicatum* L.) is the problem species.

Eurasian watermilfoil was first collected in Tulsa District on 26 June 1959 in Quannah Parker Lake on the Wichita Mountains Wildlife Refuge in southwestern Oklahoma. From these it spread, or more probably other populations were introduced until it was found in the Arkansas, Red, and Washita River drainage systems. In the early 1970's, after a survey by the Oklahoma Department of Wildlife Conservation it became apparent that the State could have a potential problem of major economic significance.

Reconnaissance surveys were conducted in 1975 and 1979 persuant to developing a State Design Memorandum. A comparison of those surveys showed that in 1975 watermilfoil was growing in 12 separate water bodies. In 1979 the total number increased to 18 with the discovery of growths in Soil Conservation Service ponds in south central Oklahoma. However, the number of infested acres decreased by almost half from 8,000 acres in 1975 to 4,300 acres in 1979.

The only Corps lake in Oklahoma infested is Robert S. Kerr, a project in the McClellan-Kerr Navigation System along the Arkansas River. The infestation there was 288 acres in 1979 after an all time high of 1,200 acres in the middle 1970's. There is a control program being carried out at that project, but the most obvious possible explanation for the decrease in the remaining acreage of infestation is that the winters of 1977-78 and 1978-79 were extremely severe freezing more of the overwintering plants than usually occurs.

Oklahoma is like a simmering pot ready to boil over and send Eurasion watermilfoil down the Arkansas and Red Rivers to the Gulf. It is because of this potential that Oklahoma is very much involved in aquatic plant control and the APCRP.

This year we will complete work on a State Design Memorandum

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* U. S. Army Engineer Division, Southwestern; Tulsa District, Tulsa, Oklahoma.

allowing local entities to receive cost-sharing in control programs. The District will continue to monitor the plant populations and conduct periodic surveys to detect possible new infestations. Measures will be taken to ensure that, insofar as possible, Oklahoma infestations will stay home.

A COOPERATIVE AGREEMENT FOR ACCOMPLISHING AN AQUATIC PLANT CONTROL PROGRAM IN WASHINGTON STATE

by

Ron Pine*

Introduction

Prior to 1975 the words "Eurasian watermilfoil" or "milfoil" were little used in the State of Washington, except by aquatic biologists. Now it has become almost a household word. Many newspaper articles have been written and spots have appeared on television describing the problems caused by milfoil and the control efforts, and airing differences of opinion on the most cost-effective and environmentally safe methods of controlling the plant.

Washington State officials first became aware of the potential extent of the problem through Dr. Peter Newroth of the British Columbia Ministry of Environment. At a presentation before the Pacific Northwest River Basins Commission, in December 1976, Dr. Newroth described infestations of milfoil in the Okanogan River lake chain in Canada, tributary to the Columbia River, and the Ministry's efforts to control it. He warned that unless steps were taken to stop the spread of milfoil it would eventually infest the Columbia River, an important fishery, irrigation, recreation, and hydroelectric resource in the Pacific Northwest. It was subsequently learned that there were infestations of milfoil in lakes Washington and Sammamish near Seattle, and in some of the Columbia River Basin irrigation project reservoirs.

A series of meetings was held by the Washington Department of Ecology with the Corps of Engineers Seattle District to discuss the Corps' cost-share aquatic plant control program authorized under Section 302 of the Rivers and Harbors Act of 1965. The Washington Department of Ecology, by authority of the Governor of the State, agreed to act as the statewide "umbrella sponsor" for the cost-share program actively seeking local sponsors to contribute the required 30 percent matching funds.

A Strawman Aquatic Plant Management Plan was subsequently prepared by WES to assist the Seattle District in developing a final work plan and to describe various control alternatives. A field reconnaissance was then conducted and a report prepared by WES describing the potential for infestation of selected waters in Washington State by Eurasian watermilfoil. A 3-year Large-Scale Operations Management Test (LSOMT) was also initiated by WES to evaluate prevention and control methodologies that might be used in the State of Washington.

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* Washington Department of Ecology, Olympia, Washington.

Ultimately, a final Aquatic Plant Management Program Design Memorandum and an Environmental Impact Statement were prepared by the Seattle District that emphasized prevention as a priority and unique feature of the Washington State program. All through this process the Seattle District Corps of Engineers encouraged the participation of, and review by, the State of Washington Department of Ecology. A final cooperative agreement was developed and signed on 15 July 1980.

The Cooperative Agreement

A considerable amount of discussion took place between the Jacksonville and Seattle Districts and the Washington Department of Ecology before it was decided that a cooperative agreement was the most appropriate cost-share vehicle for the State of Washington Aquatic Plant Prevention and Control Program. The Jacksonville District uses annual procurement contracts for the direct purchase of services from the State of Florida Department of Natural Resources in the control and eradication of waterhyacinth, alligatorweed, milfoil, and other obnoxious aquatic plants.

A cooperative agreement developed under authority of Public Law 95-224, Section 6, allows for the "transfer of money, property, services, or anything of value to the state or other recipient to accomplish" a task or work plan "authorized by Federal statute, rather than acquisition, by purchase, lease, or barter, of property or services for the direct benefit" of the Federal Government. In a cooperative agreement, substantial involvement is anticipated between the Federal agency executing the agreement and the State or local government involved. What is meant by "substantial involvement" is defined in the "OMB Guidance On Implementation of Grants and Cooperative Agreements" dated 30 September 1978, but essentially can vary from a lot to very little.

The cooperative agreement for the control of Eurasian watermilfoil between the Seattle District and the State of Washington consists of primarily two major parts: the agreement, and the detailed annual budget and work plan. The agreement defines the purpose; identifies the parties involved; describes the priority elements of the program, reimbursement procedures, and duration of the agreement; identifies the project officers representing the Corps and the State; and specifies the effective date of the agreement.

As part of the cooperative agreement, all operations carried out by the State must conform to the minimum work requirements (attached to the agreement as Appendix A) an integral part of the Agreement. Appendix A describes the eligible treatment methods for the prevention and control of milfoil, requires the State to inform residents and the public concerning treatment and any restrictions necessary, and requires supervision, inspection, monitoring, and reporting of operations. The cooperative agreement remains in force unless terminated by either party after providing 90 days advance written notice to the other.

The aquatic plant management work plan and budget is the flexible portion of the agreement. A work plan and budget must be developed annually by the State and submitted to the Seattle District for approval. It describes in detail the work to be accomplished for the fiscal year in question and an estimated budget. If subcontractors or local sponsors, other than the State, are involved, the work assigned to each is described. Although not required under the cooperative agreement, all subagreements or contracts between the State and local governments for the control and prevention of milfoil are submitted to the Seattle District for review.

Conclusions

The Cooperative Agreement was the best and least cumbersome vehicle for instituting a cost-sharing aquatic plant management program in the State of Washington. While the State Attorney General had some initial questions and concerns about certain paragraphs and phrases in the agreement, these were eventually worked out to the satisfaction of everyone. It would have been much more difficult trying to satisfy the concerns of the attorneys and our administration in negotiating a procurement contract.

One of the worthy features of the agreement is that it establishes prevention operations as the first priority in the Washington program and control operations as the second priority. The annual work plan and budget is developed accordingly, which makes it easier when cuts have to be made in the program if the desired funding for any particular year does not become available.

In conclusion, I would like to say that the cooperation of the Corps of Engineers, and particularly the Seattle District, has been a major factor in the development and initiation of a successful aquatic plant management program in the State of Washington. Much more can and will be done to prevent and control the growth of milfoil in the State of Washington; however, the legal instrument to accomplish the necessary work has been developed and efforts can now be concentrated on the actual implementation of an effective milfoil prevention and control program.

PROBLEM IDENTIFICATION AND ASSESSMENT

An Overview

by

Anthony M. B. Rekas*

Introduction

Objectives

As stated in the Aquatic Plant Control Research Program (APCRP) 5-year plan, the objectives of the Problem Identification and Assessment for Aquatic Plant Management work unit are:

- a. To develop techniques for identifying and assessing the scope of problem aquatic plant infestations.
- b. To classify the problem areas into categories related to available control methodologies.
- c. To quantify the economic and social impacts of severe aquatic plant infestations.

Research on this APCRP work unit is being conducted by the Environmental Assessment Group (EAG) of the Environmental Laboratory at the U. S. Army Engineer Waterways Experiment Station (WES).

Approach

The approach to achieving the objectives of this work unit has consisted of three sequential tasks:

- a. Task 1: Develop and evaluate rapid, site-specific and regional survey techniques to locate, identify, and map the distribution of problem emergent and submerged aquatic plant species.
- b. Task 2: Develop and evaluate a classification system for characterizing aquatic plant problem areas that can be used to select control techniques.
- c. Task 3: Develop and evaluate techniques for quantifying the economic and social impacts of severe aquatic plant infestations.

The report on this work presented at the 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review (Rekas 1980) summarized the previous WES work on Task 1 which has resulted in

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

the identification of films and filters, aerial photomission specifications, and photointerpretation techniques that are recommended for rapid surveys of emergent and submergent aquatic plant populations in site-specific situations (i.e., specific lakes and rivers). An engineer pamphlet describing the aquatic plant survey techniques for operational users is in preparation.

1980 Research Studies

Task I studies

In 1980, EAG has conducted Task I studies in widely separated geographic areas to validate the aquatic plant survey techniques applicability to regional aquatic plant surveys (Galveston District), an emergent aquatic plant survey (Mobile District), and submerged aquatic plant surveys in riverine systems (Galveston and Seattle Districts) and lakes (Seattle District and Panama Canal). The details of the Galveston District and Panama Canal studies will be presented in a subsequent paper by Mr. S. D. Parris and details of the Mobile District study will be presented by Mr. J. M. Leonard. The Seattle District studies are discussed in the following paragraphs.

The airphoto mission specifications, methodology, and preliminary results of the water penetration tests using three films, black and white (Kodak Double-X Aerographic Film, 2405), color (Kodak Ectachrome ER Aerographic Film, SO397), and color infrared (IR) (Kodak Aerochrome Infrared Film, 2443), flown at 1:5000 scale were presented at last year's meeting (Rekas 1980). Since then, the EAG has completed the photointerpretation of the 1:10,000- and 1:20,000-scale imagery. The results of the tests of the films' capability to be used to detect two sizes and two colors of targets that were diver-placed in three lakes at 5-ft depth intervals from 0- to 30-ft depths are presented in Table 1. Target detection was determined by a skilled photo interpreter using 10× magnification. The analysis indicated that black and white imagery yielded shallower detection depths than either color or color IR at all scales in all lakes and that color and color IR film, in most cases, performed equally well at all scales in all lakes. However, color imagery was easier to interpret (Table 2). In general, white targets were easier to detect than were green targets. Panels were easier to detect than were blocks, and larger scale imagery was easier to interpret than smaller scale imagery. It should be noted that water transparency, background (bottom) color, orientation of targets with respect to sun angle, and surface glitter may significantly alter the maximum depths that targets can be detected; however, these results are consistent with those reported by Lockwood et al. (1974) for similar film/filter combinations.

As a result of the previous and 1980 Task I studies, EAG personnel conclude that black and white films flown at 1:10,000 to 1:20,000 scale are most useful for regional surveys of both emergent and submergent aquatic plants. Color films flown at 1:5000 scale are more suitable for

detailed surveys of submerged aquatic plants and color IR films flown at 1:5000 scale are more suitable for detailed surveys of emergent aquatic plants. The Okanogon and Pend Oreille Rivers and Lake Osoyoos were successfully surveyed in FY 80 using color film flown at 1:5000 scale.

Task II studies

Work on the development of a site classification system began in 1979 for use in selecting one method from available aquatic plant control methodologies (Rekas 1980). Initial efforts were directed to the identification of the aquatic plant control methods that were available to, and in current use by, Corps of Engineers (CE) Districts. A review of aquatic plant control literature published through 1978 and a telephone survey of the CE Districts were conducted to compile these data (Dardeau 1981). An important element of the review and survey was the identification of the types of data that were required to conduct CE District aquatic plant control operations; e.g., Table 3 presents a list of data requirements identified by the Jacksonville District.

The FY 80 work on the site classification system was scheduled to include two concurrent studies:

a. Identification of the site characteristics that affect selection and performance of control methodologies.

b. Identification of the factors that affect the potential population level of Eurasian watermilfoil (*Myriophyllum spicatum* L.).

By November 1979 it was apparent that the magnitude and complexity of the work on either of these studies would require more time and personnel than could be supported by the available FY 80 funding. A comprehensive review of the program was conducted that resulted in a reduction in the scope of the FY 80 work. The scope of classification system work was restricted to an investigation of the environmental factors that affect establishment and growth of Eurasian watermilfoil (hereafter called milfoil) and the development of a classification system to characterize the sites where milfoil can be and has become established. The reasons for the shift in scope included:

a. The identification of site characteristics that affect selection and performance of control methodologies was currently being investigated by three existing APCRP programs, biological, chemical, and mechanical.

b. In the past 5 years, the most severe aquatic plant management problems reported by CE Districts have been with control of the submerged aquatic plant species Eurasian watermilfoil (Seattle District) and hydrilla (Jacksonville District).

c. The potential population level of the problem species is the data requirement (Table 3) for which the lease information was and is available.

d. The results of recent APCRP-funded laboratory studies on the

environmental requirements (i.e., temperature, light, nutrients, etc.) of aquatic plants (Barko 1980) could be used to evaluate the results of field studies of the same requirements.

e. The APCRP laboratory studies could use field-collected data on existing environmental conditions to establish realistic environmental gradients for scheduled laboratory evaluations of aquatic plant requirements.

The objectives of the revised FY 80 classification work were:

a. To identify the environmental factors that are expected to be important to the establishment and growth of Eurasian watermilfoil.

b. To identify the equipment and sampling techniques required to effectively collect field data on the environmental factors.

c. To develop a research plan for field data collection for implementation in FY 80.

d. To collect field data at selected sites in the United States.

To meet objective a above, the EAG prepared a list of selected environmental factors that were expected to be important to the establishment and growth of milfoil and compiled the minimum and maximum range for those factors from the literature reports on milfoil populations (Table 4). However, the literature reviewed did not include field-collected data on several of the environmental factors. For objective b, equipment was purchased and field sampling techniques were identified for the subsequent FY 80 field studies. A data collection plan was prepared and implemented in Lake Osoyoos, Washington, to satisfy objective c. The specific objective of the field plan was to evaluate the sampling equipment and techniques and collect field data (objective d) on sediment type and nutrients for comparison to the biomass of milfoil in five selected sites where milfoil occurred and five sites where it was absent (Tables 5 and 6). Analysis of these data will continue in FY 81. The sampling equipment and techniques will be described in the paper entitled "An Adaption of Existing Instrumentation Technology to Aquatic Plant Monitoring." (This paper begins on page 85 of this report.)

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Table 1

Detection of Underwater Target Panels and Blocks Using Various Scale-Imagery Combinations

		Detection Limit (Water Depth), ft			
		White		Green	
Test Site	Imagery	Panel*	Block**	Panel	Block
		Scale 1:5,000			
Lake Osoyoos					
(Secchi disk - 12 ft, lake bottom - sand)	Black and white	20	20	10	0
	Color	20	15	20	0
	Color infrared	20	10	20	10
		Scale 1:10,000			
	Black and white	15	10	5	5
	Color	20	10	5	5
	Color infrared	25	10	10	5
		Scale 1:20,000			
	Black and white	10	0	0	0
	Color	20	0	10	0
	Color infrared	20	15	15	15
		Scale 1:5,000			
Lake Whatcom					
(Secchi disk - 16 ft, lake bottom - mud)	Black and white	10	0	5	0
	Color	20	10	15	5
	Color infrared	15	15	10	5
		Scale 1:10,000			
	Black and white	10	0	0	0
	Color	15	10	10	10
	Color infrared	15	15	10	15

(Continued)

* 4 ft × 4 ft.
** 16 in. × 8 in.

Table 1 (Concluded)

Test Site	Imagery	Detection Limit (Water Depth), ft: White Panel	White Block	Green Panel	Green Block
		Scale 1:20,000			
Lake Whatcom (Continued)	Black and white	10	0	0	0
	Color	15	5	10	10
	Color infrared†				
		Scale 1:5,000			
Lake Sammamish					
(Secchi disk - 14 ft, lake bottom - sand)	Black and white	15	10	0	0
	Color	20	15	15	10
	Color infrared	15	15	15	15
		Scale 1:10,000			
	Black and white	10	10	0	0
	Color	10	10	5	10
	Color infrared	15	10	15	10
		Scale 1:20,000			
	Black and white††				
	Color	10	5	10	10
	Color infrared	15	10	15	5

† Obscured by glitter, no data.
†† No 1:20,000-scale black and white imagery was available for Lake Sammamish.

Table 2

Average Detection Depths,* Lake Osoyoos, Lake Whatcom, and Lake Sammamish

Scale-Imagery Combination	Average Detection Depth, ft			
	White		Green	
	Panel	Block	Panel	Block
Scale 1:5,000				
Black and white	15.0	6.7	5.0	0
Color	20.0	13.3	16.7	8.3
Color infrared	16.7	13.3	15.0	11.7
Average	17.2	11.1	12.2	6.7
Scale 1:10,000				
Black and white	13.3	3.3	1.7	1.7
Color	15.0	10.0	6.7	8.3
Color infrared	18.3	11.7	11.7	10.0
Average	15.0	9.4	6.7	6.7
Scale 1:20,000				
Black and white	10.0	0	0	0
Color	15.0	3.3	10.0	6.7
Color infrared	11.7	8.3	10.0	6.7
Average	11.1	4.4	7.5	5.0

* Based on data contained in Table 1.

Table 3

Data Requirements for Planning Control Programs*

Environmental Factors
Aquatic plant species present
Existing and potential population level of aquatic plants
Morphology of water body
Water depth
Streamflow (seasonal and daily trends)
Weather (seasonal and daily trends)
Obstructions (stumps, pilings, etc.)
Collection points for floating plants
Environmental constraints (critical fish and wildlife habitat, sensitive crops, etc.)
Uses of the water body (crop irrigation, water intakes, etc.)
Resource Factors
Man power (in-house, contract, or hired labor)
Available control methods (biological, chemical, mechanical)
Funds (operation and maintenance, special need)
Equipment requirements (boats, sprayers, harvesters, etc.)

* Modified from Joyce (1977).

Table 4

Maximum and Minimum Values for Critical Environmental Factors Important to the Establishment, Growth, and Spread of Eurasian Watermilfoil

Factor	Minimum Value	Source*	Maximum Value	Source*
Water parameters				
Temperature	3.9°C	B.C., W.I.B. (1979)	39.4°C	Fussell-Rutherford (1978)
Light intensity (compensation point)	335 μ Einstein/m^2/sec (20°C; 400-700 mm wavelength)	Brenkert and Amudsen (not dated)	700 μ Einstein/m^2/sec (30°C; 400-700 mm wavelength)	Brenkert and Amudsen (not dated)
Total alkalinity (hardness)	20 μg $CaCO_3$/ℓ**	Fussell-Rutherford (1978)	1210 μg $CaCO_3$/ℓ**	Perkins (1980)
pH	5.8	Brenkert and Amudsen (not dated)	9.7	Brenkert and Amudsen (not dated)
Conductivity	76 μmhos/cm**	Fussell-Rutherford (1978)	463 μmhos/cm**	Pinsent et al. (1974)
Dissolved oxygen	0.6 mg/ℓ**	Pinsent et al. (1974)	15.6 mg/ℓ**	Pinsent et al. (1974)
Water depth				
Nutrients				
N	0.00 mg/ℓ**	Scheaffer (1978)	5.0 mg/ℓ**	Scheaffer (1978)
P	<0.005 mg/ℓ**	Pinsent et al. (1974)	3.2 mg/ℓ**	Scheaffer (1978)
K	1.4 mg/ℓ**	Perkins (1980)	2.3 mg/ℓ**	Perkins (1980)
S				
Ca	2.8 ppm	Brenkert and Amudsen (not dated)	270 ppm	Brenkert and Amudsen (not dated)
Mg	5.0 mg/ℓ**	Perkins (1980)	8.7 mg/ℓ**	Perkins (1980)
Fe				
Cu				
Sediment parameters				
Particulate organic matter	1.48 percent** (dry wt) (organic carbon)	Pinsent et al. (1974)	6.5 percent+ (dry wt)	Barko and Smart (1979)
pH	6.4**	Scheaffer (1978)	8.9**	Scheaffer (1978)

(Continued)

* See References section.
** Value for entire lake, not just areas infested with Eurasian watermilfoil.
\+ Saturated, test value.

Table 4 (Concluded)

Factor	Minimum Value	Source	Maximum Value	Source
Sediment parameters (Continued)				
Nutrients				
N	0.00 ppm**	Scheaffer (1978)	0.37 ppm**	Scheaffer (1978)
P	0.01 ppm**	Scheaffer (1978)	515 ppm (total P)**	Fussell-Rutherford (1978)
K				
S				
Ca				
Mg				
Fe				
Cu				
Particle-size distribution	Sand-silt-clay 0.0-20.0-80.0+ (percent dry wt)	Barko and Smart (1979)	Sand-silt-clay 60.0-2.5-37.5+ (percent dry wt)	Barko and Smart (1979)
Soil type				
Wave and current parameters				
Wave height				
Wind direction				
Wind velocity				
Current direction				
Current velocity				
Other parameters				
Bottom topography				
Biomass of Eurasian watermilfoil	32 g/m^2 (dry wt) (seasonal value)	Grace and Wetzel (1978)	1146 g/m^2 (dry wt)++ (seasonal value)	Grace and Wetzel (1978)
Meristem production of Eurasian watermilfoil				
Biomass of competing plant species			1950 g/m^2 (dry wt) (*Najas guadalupensis*)	Brenkert and Amudsen (not dated)

** Value for entire lake, not just areas infested with Eurasian watermilfoil.
+ Laboratory test value.
++ Grace and Wetzel (1978) state that this value reported for Wisconsin in 1968 was possibly an overestimate because of the small number of samples.

Table …

Sediment Samples … 1980

Element Analyses	Sample Range Min–Max Watermilfoil Present	Sample Range Min–Max Watermilfoil Absent	Watermilfoil Present 1*	Watermilfoil Present 2	Watermilfoil Present 3	Watermilfoil Present 5	Watermilfoil Absent 1*	Watermilfoil Absent 6	Watermilfoil Absent 7	Watermilfoil Absent 8	Watermilfoil Absent 9	Watermilfoil Absent 10*	Average Values … Mean Present	Average Values … Mean Absent
Grain size analysis, percent retained on standard sieve														
No. 10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.63	[illegible]	1.64	[illegible]	5.56	[illegible]	[illegible]	[illegible]	[illegible]
No. …	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.61	[illegible]	[illegible]	[illegible]	16.04	[illegible]	[illegible]	[illegible]	[illegible]
No. …	[illegible]	[illegible]	[illegible]	[illegible]	69.8	[illegible]	63.46	[illegible]	[illegible]	33.62	[illegible]	[illegible]	[illegible]	[illegible]
No. …	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.18	[illegible]	[illegible]	[illegible]
No. …	[illegible]	[illegible]	[illegible]	[illegible]	94.88	[illegible]	100.…	100.04	41.82	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
No. …	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.60	[illegible]	[illegible]	56.18	12.94	[illegible]	[illegible]	[illegible]	[illegible]
Volatile solids percent	[illegible]	[illegible]	[illegible]	1.46	1.68	1.35	[illegible]	[illegible]	1.58	2.60	[illegible]	[illegible]	[illegible]	[illegible]
Classification (… Soil … Survey)	--	--	SP-SM	SP	SP	SM	SP	SP	SL or ML	SM	SM or S…			
pH …	[illegible]	[illegible]	7.67	7.60	[illegible]	7.62	7.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Bicarbonate alkalinity	1.1–…	[illegible]	1.30	1.46	1.46	[illegible]	[illegible]	[illegible]	1.80	1.88	[illegible]	[illegible]	[illegible]	[illegible]
Total organic carbon, …	500–19,400	[illegible]	[illegible]	1,640.…	3,320.…	6,250.…	3,500.…	4,780.…	8,740.…	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ammonia-N …	[illegible]	[illegible]	9.97	3.54	4.16	13.27	6.1	[illegible]	32.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nitrate-N …	[illegible]	[illegible]	--	[illegible]	0.634	2.13	1.04	0.46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total Kjeldahl nitrogen …	[illegible]	[illegible]	914.0	360.0	[illegible]	781.67	970.0	[illegible]	1,540.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
… phosphate … as P	[illegible]	[illegible]	[illegible]	1.13	0.74	2.40	[illegible]	[illegible]	[illegible]	[illegible]	1.50	[illegible]	[illegible]	[illegible]
Total phosphate … as P	[illegible]	231–1,610	514.0	[illegible]	536.6	[illegible]	505.3	[illegible]	[illegible]	714.2	[illegible]	[illegible]	[illegible]	[illegible]
… solids …	[illegible]	[illegible]	[illegible]	14,600.0	16,800.0	13,500.0	50,333.3	[illegible]	35,800.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* … samples.

Table 6

Plasma Spectrographic Analysis of Sediment Samples - Lake [illegible], 198[illegible]

[illegible]	Sample Range, µg/g Watermilfoil Present	Sample Range, µg/g Watermilfoil Absent	Average Values Per Plot, µg/g Watermilfoil Present 1	2	3	5	18	Watermilfoil Absent 6	[illegible]	[illegible]	[illegible]	[illegible]	Average Values for Lake, µg/g Present	Average Values for Lake, µg/g Absent
[illegible]	[illegible]	49,[illegible]	[illegible]	[illegible]	65,440.0	95,840.0	73,500.0	66,960.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	7.5*	7.5*	7.5*	7.5*	7.5*	7.5*	7.5*	7.5*	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1,126.0	1,044.0	1,003.3	913.3	994.8	838.0	957.0	1,17[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.15*	0.15*	0.15*	0.15*	0.15*	0.15*	0.15*	0.15*	0.15*	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	25.0*	25.0*	25.0*	25.0*	25.0*	25.0*	25.0*	25.0*	25.0*	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.25*	1.25*	1.25*	1.25*	1.25*	1.25*	1.25*	1.25*	1.25*	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]-16,[illegible]	[illegible]	[illegible],980.0	21,900.0	24,157.0	26,900.0	21,060.0	99,160.0	33,900.0	40,320.0	25,[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	24-[illegible]	[illegible]	29.6	68.4	26.9	173.3	76.4	43.8	37.2	54.6	124.3	53.8	62.4
[illegible]	[illegible]	[illegible]-24	[illegible]	8.2	10.2	9.1	4.7	7.0	16.6	11.6	15.8	1.0*	9.2	11.[illegible]*
[illegible]	[illegible]	[illegible]	12.0	8.4	5.0	10.4	18.0	10.2	41.2	16.6	30.6	[illegible]	10.2	23.8
Iron	[illegible]	[illegible]	16,[illegible]	21,000.0	16,560.0	18,557.0	21,700.0	17,180.0	33,600.0	23,660.0	38,100.0	24,1[illegible]	15,620.8	27,[illegible]
[illegible]	[illegible]	[illegible]	135.3*	4.0*	4.0*	4.0*	20.7*	4.0*	4.0*	4.0*	4.0*	7.0*	28.0*	4.39*
Magnesium	[illegible]	[illegible]	[illegible]	7,[illegible]	5,960.0	6,342.9	7,333.3	5,880.0	1,364.0	9,040.0	14,520.0	7,7[illegible]	6,404.2	7,7[illegible]
Manganese	[illegible]	341-[illegible]	349.[illegible]	337.4	414.4	460.7	581.7	410.8	667.6	360.2	847.0	[illegible]	465.9	625.1
Molybdenum	[illegible]	[illegible]	[illegible]*	2.0*	13.4*	2.0*	2.0*	9.6*	12.8	6.2*	3.8	3.[illegible]*	5.2*	6.6*
Nickel	[illegible]	[illegible]	13.[illegible]	12.4	9.0	12.3	22.0	13.[illegible]	27.4	16.4	27.6	14.7	13.4	21.[illegible]
Phosphorus	[illegible]	1,[illegible]-4,[illegible]	1,492.[illegible]	2,304.[illegible]	2,022.0	1,866.4	2,103.0	1,808.0	2,494.0	2,440.0	3,343.[illegible]	2,046.7	1,457.2	[illegible]
Potassium	[illegible]	[illegible]	14,300.0	16,560.0	16,680.0	17,685.7	14,933.3	19,280.0	14,760.0	17,300.0	20,700.0	18,333.3	17,000.[illegible]	18,139.2
[illegible]	[illegible]	[illegible]	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*
[illegible]	[illegible]	13,[illegible]-26,400	22,[illegible]	25,[illegible]	23,800.0	24,057.1	22,233.3	24,160.0	16,600.0	21,240.0	22,740.0	22,400.[illegible]	23,[illegible]	21,343.[illegible]
[illegible]	[illegible]	46[illegible]-[illegible]	521.0	542.6	483.2	537.4	535.3	496.[illegible]	618.[illegible]	596.8	556.6	537.[illegible]	534.6	563.[illegible]
[illegible]	[illegible]	[illegible]-30.0	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	15.0*	[illegible]*	15.[illegible]*
[illegible]	[illegible]	[illegible]-3,160	1,557.5	2,432.0	2,168.0	2,162.0	2,399.3	2,122.0	3,274.0	2,672.0	4,364.0	2,401.[illegible]	2,148.4	3,[illegible]
[illegible]	[illegible]	42-132	44.5	63.2	54.0	55.1	81.7	55.2	97.4	68.8	113.4	56.7	58.1	54.[illegible]
[illegible]	15-[illegible]	17-[illegible]	22.0	44.8	34.4	24.7	43.7	23.0	61.6	49.8	86.4	49.[illegible]	32.4	[illegible]

* [illegible] one or more values below the detection limit. Averages were calculated using one half of the value of the detection limit.

PROBLEM IDENTIFICATION AND ASSESSMENT

Development of Techniques for Large-Area Surveys of Aquatic Plants in Panama and Texas

by

Stephen D. Parris*

Background

The WES Environmental Assessment Group (EAG) is conducting research to develop rapid survey techniques to locate, identify, and map the distribution and character of emergent and submersed aquatic plant species. During FY 80 two field tests were scheduled to determine the applicability of previously developed aerial photomission specifications. A test of the best film/filter combinations for detecting submersed hydrilla was scheduled for Panama, and a test of the application of the rapid survey techniques to large-area problems was initiated in Texas in the Galveston District. The objectives of these tests were to develop improved photomission specifications to fit the characteristics of each area, and, in the case of the Galveston District, to develop and refine the survey techniques for use in an overall District-wide aquatic plant problem-assessment program.

Panama

Problem

Since 1976, the WES has maintained an aquatic plant control assistance program for the Panama Canal and Gatun Lake. The program is sponsored by the Panama Canal Commission (PCC), formerly the Panama Canal Company.

An important part of the program was the aerial photographic surveys in 1977 and 1979 to determine the location and areal extent of hydrilla in Gatun Lake. Color infrared (IR) photography was obtained at a scale of 1:24,000 in both years. Photointerpretation revealed significant areas of the lake had been invaded by hydrilla, but it was not possible to determine two important factors: (a) the maximum water depth in Lake Gatun at which hydrilla can be detected on the color infrared imagery (i.e., maximum detection depth), and (b) whether hydrilla was growing in

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* U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Lake Gatun at depths greater than the maximum detection depth. Since the distribution of submersed hydrilla was of primary interest, a field visit was made in March 1980 to determine the water-depth limit for hydrilla growth in Lake Gatun. Ground studies were scheduled at the same time that aerial photography was to be obtained at three altitudes with three film types over lake areas where detection targets had been placed on the lake surface and at water depths ranging from 5 to 30 ft.

Test plans

The remote sensing experimental design was based on a similar experiment conducted in the Seattle District during 1979.* Detection target panels of two sizes, 4 ft by 4 ft and 8 in. by 16 in., were painted green or white and one of each type was placed on the lake surface and at 5-ft intervals to a maximum depth of 30 ft. The target panels and adjacent areas were to be photographed with black and white, true color, and false-color IR photography at scales of 1:6,000, 1:12,000, and 1:24,000. Arrangements were made with the Inter-American Geodetic Survey (IAGS) to perform the photomission.

In the areas adjacent to the targets, selected colonies of hydrilla were to be characterized for the purpose of determing maximum depth of growth (Figure 1). Length and width of the colonies were to be measured with a Leitz 24-in. split-image rangefinder, and submersed portions of the colonies identified with a recording fathometer (Figure 1). Areas where hydrilla was 5 to 10 ft beneath the water surface were of particular interest, as the limit of detection with the three films was estimated to be in that range of water depth.

Scheduling of the field test was of critical importance. The rainy season in Panama is unsuitable for aerial photomissions due to daily rain showers and continuous cloudy conditions. After consultation with experts in the IAGS, the Instituto Geografico Nacional, and the PCC, the period of 24 March to 4 April 1980 was selected. It was the consensus that, although the time selected was near the end of the dry season, the weather would still be suitable for the mission. The late starting date would also allow WES sufficient time to complete planning, equipment preparation, and coordination activities.

Test results

Photography. Unfortunately, the assessment of the expected weather conditions during the scheduled photomissions was optimistic. Clouds and haze associated with the rainy season obscured the study sites. Although target panels were in position on 26 March as scheduled, photography could not be obtained. The photomission and associated ground studies

* R. L. Lazor, and Dardeau, E. A., Jr. 1980. "Prevention as an Aquatic Plant Management Method," Proceedings, Fourteenth Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, Miscellaneous Paper A-80-3, pp 213-224, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

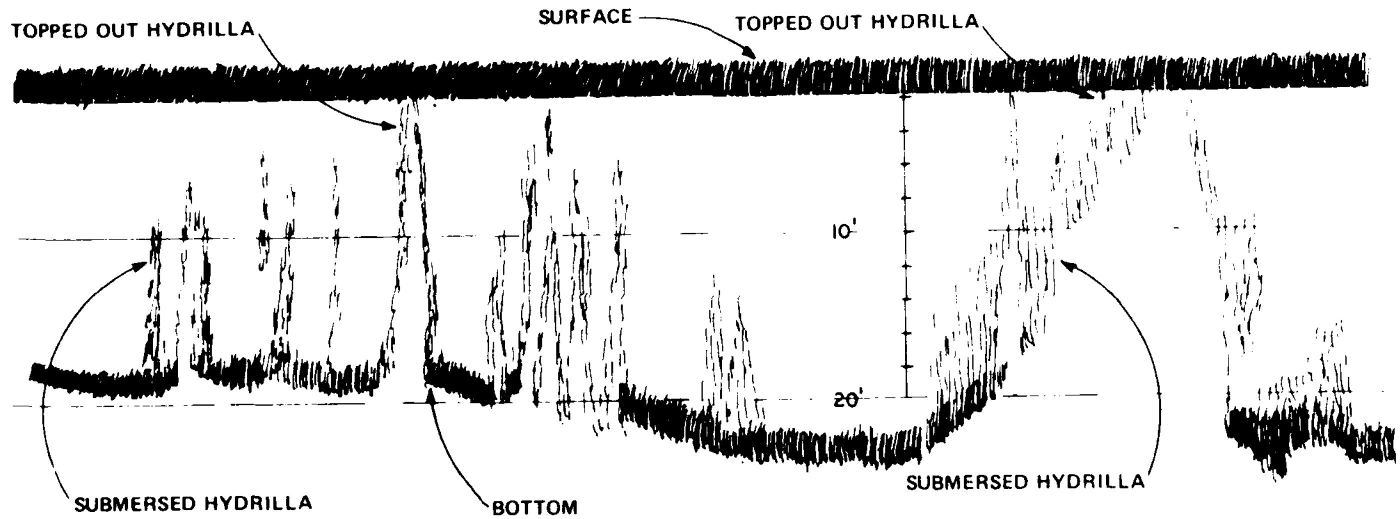

Figure 1. Fathometer transect of hydrilla in Gatun Lake

were rescheduled for the December 1980-February 1981 time period, after the end of the rainy season.

Field data collection. Even though the photomission was postponed, the WES field team obtained valuable information on the depth of growth of hydrilla colonies and the distribution of submersed hydrilla, which is applicable to 1977 and 1979 imagery. Fathometer data indicated large areas of submersed hydrilla with tops at a maximum of 15 ft beneath the water surface. Irregularly distributed sprigs of hydrilla less than 3 ft in length were found growing at a maximum water depth of 30 ft by a PCC diver.

The data indicated that hydrilla can survive in Gatun Lake at depths between 20 and 30 ft, but only develops extensive submersed beds or topped-out surface mats when water depths are 20 ft or less. Based on these findings, two basic types of hydrilla colonies were identified in Gatun Lake (Figure 2).

Type 1 colonies are characteristic of backwater areas and island shorelines. Beyond these areas the lake bottom drops sharply into submerged valleys or old river channels over 20 ft in depth. Topped-out mats form in the shallows and may be small or extensive, depending on the bottom topography. There is very little submersed hydrilla that does not develop surface mats at these sites. Color IR aerial photography of these areas shows the topped-out mats but no submersed hydrilla, which is an accurate portrayal of the situation.

Type 2 colonies are found in open water of the lake, generally in areas where dredged material was deposited during canal construction and maintenance activities. The dredged material disposal created extensive areas of level topography 10 to 15 ft deep, forming an excellent substrate for hydrilla establishment and growth. The result is hundreds of acres of submersed and topped-out hydrilla. Wave action appeared to be an important reason hydrilla did not generally form topped-out mats over large areas on the dredged material disposal areas. It was noted at Dump 10 that specific colonies changed height due to wave action and perhaps changes in current, sometimes extending to or near the water surface and at other times being 5 to 10 ft beneath the water surface. These height changes coupled with substrate variations produced a discontinuous growth pattern over hundreds of acres of hydrilla in the disposal areas. This pattern was noticeable on 1977 and 1979 photography, giving the disposal areas a speckled appearance.

Observations

Even though areas of submersed hydrilla were located, there was no way to determine how much the beds had changed since the aerial photography was taken. Also, it was apparent that the locations of the submersed beds had to be determined accurately in reference to shoreline position identified on recent photography. Therefore, an AGNAV positioning system was acquired that had the capability to establish or to relocate positions by coordinates over water. The AGNAV system uses two onshore signal repeaters and a boat-mounted unit that continuously displays

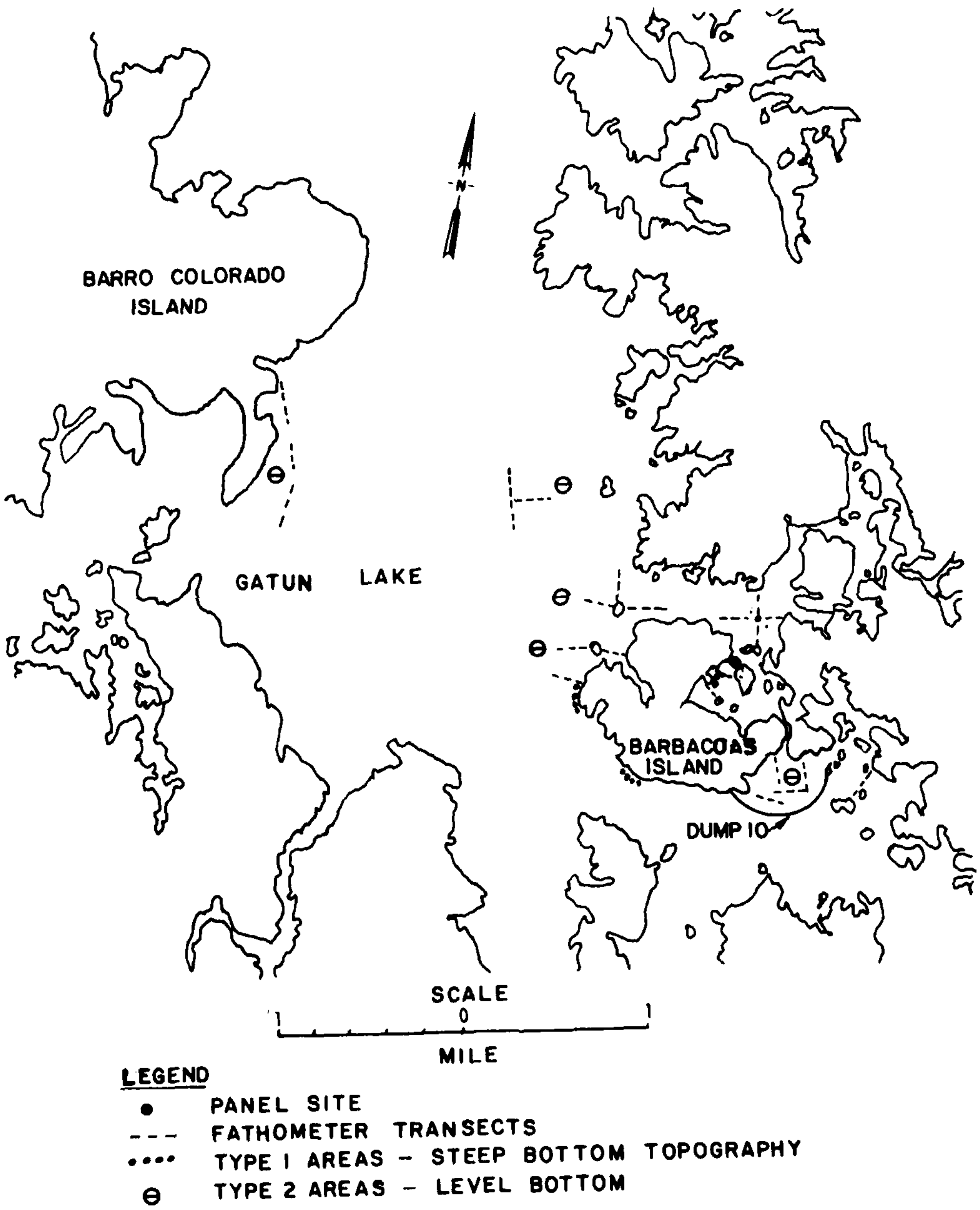

Figure 2. Location of panel site and transects in Gatun Lake

coordinate data. This equipment will be used for accurate position determination during the rescheduled photomission and ground-data collection.

At the present time, only estimates can be made of the water depth in Gatun Lake that is the limit for detecting submersed hydrilla by remote sensing. In both type 1 and 2 hydrilla colonies, the estimated limit is between 5 and 10 ft with the limit in the less turbid backwater areas perhaps several feet deeper than in the dredged material disposal areas.

Galveston District

In April 1980 the Galveston District contacted WES for assistance with their aquatic plant control program. One specific concern was the extent and location of problem aquatic plant infestations within the District. The EAG saw this request as an opportunity to integrate the survey techniques developed during the past several years and to produce not only an improved and updated regional aquatic plant survey, but also a monitoring sequence applicable to planning future regional surveys in the Galveston District.

The Galveston Disrict includes the entire Texas gulf coast, extends inland over 100 miles (Figure 3), and contains a diversity of aquatic ecosystems: freshwater and saltwater marshes, estuaries, swamps, rivers, creeks, reservoirs, and natural lakes. Three species of aquatic plants are of primary interest: hydrilla (*Hydrilla verticillata*), waterhyacinth (*Eichhornia crassipes*), and alligatorweed (*Alternanthera philoxeroides*). These species exhibit a variety of growth forms: hydrilla is a rooted submersed aquatic species; waterhyacinth is a floating species; and alligatorweed is a rooted emergent species. The variety of topographic features and associated plant communities in the District presents an opportunity to verify the aquatic plant survey and assessment methodology in very different test environments than that of Gatun Lake.

Test plan

Two primary objectives have been specified for the assistance program:

a. Use remote sensing and ground reconnaissance methodology to develop a problem-assessment plan that can be implemented operationally by the Galveston District.

b. Update the Galveston District portion of the 1971 General Design Memorandum, "Aquatic Plant Control and Eradication Program, State of Texas."

Site selection

The selection and photography of several study areas representative of the aquatic vegetation habitats in the District were completed

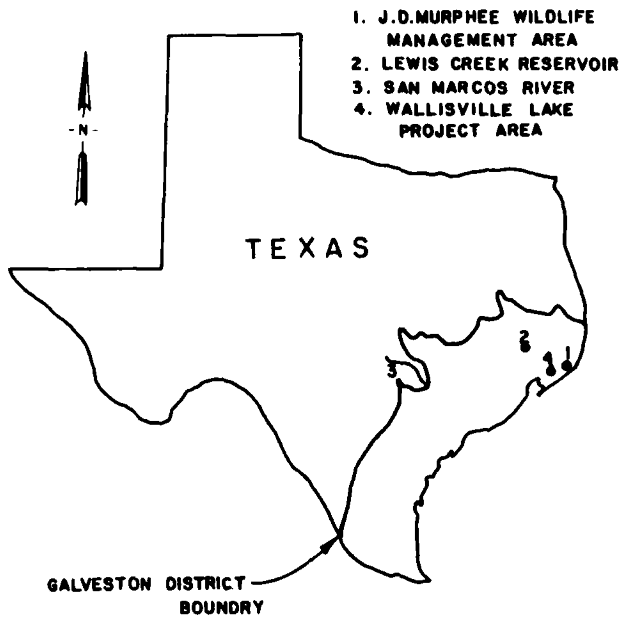

Figure 3. Location of study areas in Texas

during the 1980 growing season. Four areas were selected: the J. D. Murphee Wildlife Management Area near Port Arthur, which had alligatorweed and waterhyacinth populations; the Wallisville Lake project area near Anahuac with reported alligatorweed and waterhyacinth populations; Lewis Creek Reservoir near Conroe, which had an established hydrilla population; and the San Marcos River at San Marcos with hydrilla and waterhyacinth populations. (Note: the San Marcos River is within the Fort Worth District, but was included as a study area since it drains directly into the Galveston District as a tributary of the Guadalupe River system.)

Photomission

The Galveston District study required a wide range of survey and assessment capabilities for aquatic plant habitats because of the diversity of the plant species. Color IR imagery is used extensively to distinguish floating and emergent aquatic plant species and terrestrial vegetation types. True color imagery is also very suitable and has the advantages of being less expensive, operationally easier to use in a photomission than color IR film, and generally more easily and reliably interpretable for submerged aquatic plant growth. The J. D. Murphee area, which has a heterogeneous variety of aquatic and terrestrial plant species, was considered a good study site for a comparison of the detection capabilities of true color and false-color IR film.

For this reason, both color IR and true color films at 1:12,000 scale were used for the J. D. Murphee area. The Wallisville Lake area was flown with true color at 1:12,000 scale.

Water depth penetration is an important consideration in surveys for hydrilla, and, in areas where hydrilla colonies are not extensive, photographic scale may also be critical. For these reasons, Lewis Creek Reservoir was photographed with true color at scales of 1:12,000 and 1:6,000 and the San Marcos River with true color at 1:6,000 scale.

Ground reconnaissance

A WES field team visited the test areas late in September. The vegetation types in the study areas were recorded, and marker panels that would be visible in the photography were placed near representative vegetation types at critical locations in the J. D. Murphee area and the Lewis Creek Reservoir. The photomission was flown on 2, 9, and 10 October 1980.

Data collection

J. D. Murphee area. The J. D. Murphee Wildlife Management Area is coastal freshwater marshland, generally without surface water during a large part of the year. In addition to alligatorweed and waterhyacinth, two other problem aquatic plant species were identified in the area: waterpennywort (*Hydrocotyle umbellata*) and frog's bit (*Limnobium spongia*). Primary problem locations are in the canals that drain the area. A total of six marker panels consisting of white bed sheets suspended from long stakes were placed in six vegetated areas: four in a colony representative of each species and two in areas of mixed vegetation.

Lewis Creek Reservoir. Lewis Creek Reservoir is an impoundment used as a source of cooling water for the Lewis Creek Power Plant owned by Gulf States Utilities Company (GSUC). The water in the impoundment is relatively clear (Secchi disk reading of 14 ft), and early this past summer about 80 percent of its 1100 acres was covered by hydrilla.* Although there was a partial dieback late in the summer, during late September hydrilla covered 50 to 60 percent of the surface area of the reservoir.

As in Panama, the problem in Lewis Creek Lake was to determine how much submersed hydrilla was present. Four marker panels were placed adjacent to hydrilla beds in the lake. Fathometer readings of adjacent submersed hydrilla growth were made and will be used to correlate photo-interpreted hydrilla distribution with depths and locations of hydrilla established by the field team.

The hydrilla problem at Lewis Creek Lake is especially interesting due to the recent dieback of hydrilla. Diebacks of hydrilla of this magnitude (about 30 percent of the total growth) have been rarely

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* Personal Communication, September 1980, Mr. Bobby Clay, Biologist, GSUC, Willis, Texas.

reported in the scientific literature or elsewhere. Sam Houston State University has conducted water quality studies at Lewis Creek Lake for the past several years. Currently, Dr. James DeShaw of the University is analyzing the data for any correlations between water quality parameters and the dieback and subsequent regrowth. He observed a noticeable drop in pH at the time of dieback and a subsequent rise in pH during regrowth.*

San Marcos River. The headwaters of the San Marcos River start at a group of springs in the city of San Marcos in south-central Texas between Austin and San Antonio. The headwater is derived almost entirely from a spring flow of 200 million gallons a day and has an extremely clear, stable ecosystem in the upper reaches. An abundance of aquatic plants of a variety of species occur in the river. Hydrilla is the problem plant of most concern, but waterhyacinth is also well established in the system.

There are two areas of dense hydrilla growth in the San Marcos River. The headwaters area from Spring Lake downstream about 1 mile to the Houston Street Bridge is heavily infested. Hydrilla and other aquatic vegetation as regularly harvested in the Aquarena Spring Amusement Park on Spring Lake to maintain open water for scheduled activities. The other heavily infested area is in the rearing ponds of the State fish hatchery located adjacent to the river about 5 miles from the headwaters. The river is the hatchery water source, and consequently hydrilla has become established throughout the rearing ponds.

One objective of the ground-truth mission on the San Marcos River was to determine how far downstream hydrilla had become established. Hydrilla had been reported in the upper 5 or 6 miles, but the status farther downstream was unknown.** The river was surveyed by the field team traveling in a canoe from Spring Lake to Martindale, about 16 river miles. Unfortunately, heavy rains occurred shortly before the survey, and the river was high and turbid, reducing the probability of detecting submerged hydrilla. A small colony was found south of Pecan Park, about 10 miles below the headwaters, but similar colonies could have been overlooked. The survey did confirm that the greatest biomass of hydrilla was established within 5 miles of the headwaters.

Wallisville Lake area. Wallisville Lake is an authorized Corps reservoir project located east of Houston near the town of Anahuac, Texas. Construction has been halted by litigation for the past several years. The project area is composed of approximately 20,000 acres of marshes and swamps, with waterhyacinth and alligatorweed reported to be problem species.

Ground-truth evaluation was limited to a small area adjacent to

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* Personal Communication, Sept 1980, Dr. James DeShaw, Sam Houston State University, Huntsville, Texas.

** Personal Communication, 1980, Lou Guerra, Chief, Noxious Vegetation Section, Texas Parks and Wildlife Commission, San Antonio, Texas.

Interstate 10, part of the southern portion of the project that was photographed during the aerial photomission. Several areas characterized by uniform dense waterhyacinth colonies and an area containing submersed coontail (*Ceratophyllum demersum*) surrounded by waterhyacinth were selected for use as ground control in photointerpretation. Alligatorweed colonies were not accessible and therefore were not included. The selected ground-control locations will be carefully studied on the imagery when it is received and prior to photointerpretation.

Proposed FY 81 Work

Panama

The photomission will be flown after the end of the current rainy season, probably in late January. An EAG field crew will be onsite to obtain data on ambient and subaqueous light conditions, hydrilla distribution, and structural characteristics.

The biannual aerial aquatic plant survey of Gatun Lake is due in FY 81, and the EAG will suggest that it coincide with the WES photomission to obtain imagery for comparative evaluation. The recommended film for the FY 81 survey is true color based on the results of FY 79 film evaluations conducted for the Seattle District.* The EAG will prepare a base map of hydrilla distribution and determine the number of surface acres of hydrilla.

Galveston

The main thrust of the Galveston study will be the development of a problem-assessment plan for the FY 81 growing season. Comparisons of the FY 80 imagery and ground-control data obtained at the time of the overflight will be made to develop the optimal aerial photomission specifications. Data from these comparisons also will be used to determine schedules and manpower requirements for conducting photomissions and ground-truth surveys in FY 81. A priority ranking of water bodies will be developed for survey purposes where water bodies of primary interest to the District and most likely to develop aquatic plant problems will be assigned a high priority. When completed, this project is expected to result in improved techniques for District-wide aquatic plant surveys and an updated assessment of aquatic plant control problems in the Galveston District.

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* Lazor and Dardeau (1980).

PROBLEM IDENTIFICATION AND ASSESSMENT

Boat and Aerial Surveys of Giant Cutgrass in Lake Seminole

by

James M. Leonard*

Background

Lake Seminole was created by the closure of the Jim Woodruff Dam on the Apalachicola River downstream of the confluence of the Flint and Chattahoochee Rivers. The 37,500-acre eutrophic lake is located on the common border of Georgia, Florida, and Alabama. The U. S. Army Engineer District, Mobile, operates this project for navigation, electric power generation, and recreation. Heavy silt and nutrient inflow from the Flint River, the Chattahoochee River, Spring Creek, and Fish Pond Drain, coupled with the inundated limestone sink ponds of the river basin, create an ideal environment for numerous aquatic plants. Giant cutgrass (*Zizaniopsis miliacea*) has become a major problem along the 250-mile shoreline of the lake.

As a consequence of the prolific aquatic plant growth, an aquatic plant control program has been practiced in the lake area for the past several years. An inventory of the locations and acreages of the plant populations was made in the summer of 1979 to plan control operations and to establish a baseline from which to monitor the plant populations periodically following control activities, and to determine the effectiveness of the control methods.

Lake Seminole was selected as a WES test site for an aerial photographic survey of emergent aquatic plants. The aerial photographic survey work was done at WES as part of the Aquatic Plant Control Research Program's (APCRP) evaluation of assessment techniques. The boat survey work was performed as a routine assessment procedure for giant cutgrass by the Lake Seminole Resource Manager's Office. The acquisition of information concerning the boat survey method offered the WES an opportunity to compare results of the two survey methods.

Purpose and Scope

The WES study had two major objectives. The primary objective was

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

to map the distribution of giant cutgrass in Lake Seminole by controlled photointerpretation and to determine the area occupied by the plant species. The secondary objective was to perform a comparative analysis of the costs and results of the boat and remote sensing methods for inventorying and monitoring the giant cutgrass population.

Boat Survey

Minimal requirements for performing a boat survey of this type are skilled personnel, preferably with biological training, who are familiar with the area and accurate maps or aerial photographs of the area of interest. The boat survey of giant cutgrass in Lake Seminole was performed by highly qualified, experienced personnel from the Reservo r Manager's Office using a 1:24,000-scale black and white semicontrolled photomosaic.

The objectives of the boat survey were to determine the location of the cutgrass and to estimate the amount of herbicide needed to conduct the control operation. For these objectives, exact positioning and area measurements were not considered essential.

The survey procedure consisted of cruising along the lake and island shorelines in a small boat and marking the occurrence of cutgrass on the photomosaic. The estimates of surface area occupied by cutgrass were inflated in many instances to correspond to the minimal area (swath width) that can be treated with herbicides using the selected application methods. For example, if a band of cutgrass along the shoreline was 6 ft in width, the width was increased to about 10 ft to account for the minimum swath width allowable using the applicator technique.

Personnel required to perform this survey consisted of a boat operator and a trained biologist. Surveying the entire lake required 25 working days. The surface area covered by cutgrass at each location was estimated based on visual observations and the minimum-area constraint for herbicide application and was recorded on the map sheets. The field product was a map showing the areas to be treated. Areal calculations were made in the office using the boundaries marked on the map during the boat survey. Marked boundaries were traced with a polar planimeter to determine the surface area of cutgrass. The final products of the boat survey were a map displaying locations of cutgrass and an estimate of the total area for herbicide treatment.

It should be noted that there are other resource management activities that could be conducted concurrently with a boat survey. If the survey is performed the same way during subsequent years, population trends could be estimated. Observations as to the status of other plant communities and the changing ecology of the lake could also be made during such surveys.

Aerial Photographic Survey

The aerial survey method included:

a. An aerial photomission.

b. Limited field data collection for ground control.

c. Photointerpretation.

d. A visual check of the photointerpreted map of cutgrass from a fixed-wing aircraft.

Three control sites were selected for laying out reference markers and for surveying the perimeters of cutgrass colonies. Selection of the control sites was based on the presence of cutgrass in full aerial view and accessible by boat.

At each control site three reference markers were positioned to form the vertices of a triangle adjacent to cutgrass colonies. The markers were constructed by crossing two 3- by 10-ft strips of fluorescent pink plastic fabric at each vertex. The markers were supported with wooden poles at or above the water surface. A small boat equipped to measure distance and azimuth was anchored in the triangle at a point equidistant from the three vertex markers. A person in waders positioned a range pole at successive locations around the perimeters of adjacent cutgrass colonies until the extent of each colony was defined. Personnel in the anchored boat recorded the distance and azimuth of each range-pole position. Colony size and location were determined in this manner with accuracies of ± 10 ft at all three of the control sites.

The photomission was completed on 29 October 1979, 1 week after the reference markers were put in place and adjacent cutgrass colonies surveyed. Kodak Aerochrome 2448 color film was selected for the photomission. The product delivered was color positive transparent roll film with a 9- by 9-in. frame format at a nominal scale of 1:24,000 for the entire lake. A more precise scale for the photography was determined using the reference markers at each control site.

Interpretation of the imagery was done by WES. The interpreter first located all three sets of reference markers on the photography and the nearby cutgrass colonies that were surveyed in the field. Using the known locations of cutgrass as photointerpretation keys, the location and extent of cutgrass were interpreted over the entire lake.

A semicontrolled photomosaic of Lake Seminole constructed at a scale of 1:24,000 from black and white 1979 aerial photography was obtained from the Mobile District. A 1:24,000-scale base map of the lake shoreline and islands was traced from the photomosaic onto a transparent mylar overlay. The color film positive transparencies were placed under the overlay, and the cutgrass boundaries were interpreted and added to the base map. In those cases where the scales of the base map and color imagery were not in sufficient registration, a Bausch and Lomb Zoom Transfer Scope (ZTS) was used to register the two images optically.

After recording all areal boundaries of cutgrass vegetation on the base map, the areas occupied by cutgrass were measured. Area measurements were made using the Bruning Aeragraph Chart No. 4849, counting the number of dots randomly distributed within the areas mapped as cutgrass, and dividing the total number of dots by 100 to obtain the total area in square inches occupied by cutgrass. The area in acres was calculated using the following equation:

$$A_a = \frac{\text{No. of dots}}{100} (91.8270)$$

where

A_a = area, acres

100 = factor specified for the Areagraph Chart No. 4849

91.8270 = acres per square inch at a map scale of 1:24,000

(Accuracies of at least 97 percent are maintained in determining areas with Areagraph Chart No. 4849.)

The final photointerpreted map of cutgrass areas was checked by observations made from a fixed-wing aircraft flying at an altitude of 500 ft. As a result of this aerial reconnaissance, minor changes and additions were made to the map. These changes consisted mostly of including colonies that were too small to be detected on the photography. The net change in area occupied by cutgrass was a 10 percent increase for a grand total of 2603 acres.

The products from the aerial photographic survey were as follows:

a. Field measurements of the locations and boundary points of cutgrass occurrences at three ground-control sites at the time of the survey.

b. A mylar base map produced from a 1:24,000-scale black and white photomosaic of the entire lake.

c. A final map of verified locations and areal extent of giant cutgrass for a specified date.

d. Documented measurements of lake area covered by giant cutgrass for a specified date.

The aerial photographs contained much more information than was used in this study. The photographic record will be available in the future, should a need arise for historical data on occurrence and distribution of other aquatic and terrestrial plants.

Discussion

Because the basic objectives of each survey were different, a

comparison of variations in acreage estimates is not considered to be valid. The aerial survey method produced a measurement of actual surface area covered by cutgrass, whereas the boat survey produced an estimate of cutgrass acreage requiring treatment.

There are some comparisons between the two methods that do bear consideration. The advantages and disadvantages presented in Table 1, in general, apply to most ground and aerial surveys. Cost estimates were based on information supplied by resource management personnel at Lake Seminole and the actual WES costs. The costs of the two methods on a per-acre basis were calculated based on the size of the lake (37,500 acres) and were adjusted for current (1980) costs of materials and personnel. Comparative unit costs were 5 cents/acre for the aerial photographic survey and 12.6 cents/acre for the boat survey.

Acknowledgements

The WES wishes to express its gratitude to Angus Gholson, Resource Manager, and Joe Kight, Park Manager, of the Lake Seminole Resource Manager's Office, U. S. Army Engineer District, Mobile, Chattahoochee, Fla., for their assistance and support with this study. Appreciation is also extended to Harold Null, Survey Branch, U. S. Army Engineer District, Mobile, Mobile, Ala., for his assistance in obtaining the photographic products used in this study.

Table 1

Comparison of Boat Surveys and Aerial Surveys

Boat Survey	Aerial Survey
Advantages	
Done by in-house staff	Low cost (5¢/acre)
Other management objectives can be accomplished simultaneously	Rapid data acquisition and update capability
Documents population trends	Provides photographic records for future reference
Disadvantages	
Comparatively high cost (12.6¢/acre)	Some cutgrass not visible from the air
Limited documentation	Requires training in aerial photointerpretation
Subjective estimates of location and areal coverage of cutgrass	Requires skilled personnel (biologist)
Acquisition or updating requires 5 weeks	

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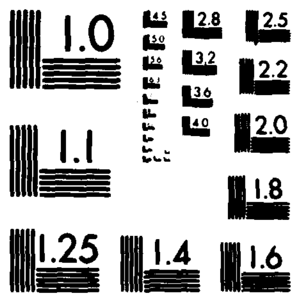

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PROBLEM IDENTIFICATION AND ASSESSMENT

An Adaption of Existing Instrumentation Technology to Aquatic Plant Monitoring

by

Anthony M. B. Rekas* and Philip D. Bailey*

Introduction

One of the objectives of the APCRP work unit entitled "Problem Identification and Assessment for Aquatic Plant Management" is the development of techniques for identifying and assessing the scope of problem aquatic plant infestations. This work has required the development of techniques to locate, identify, and map the present distribution of problem emergent and submerged aquatic plant species (using remote sensing techniques) and the development of techniques to assess the existing and possible future biomass and distribution of the plant species in individual water bodies (using existing or newly developed field sampling techniques and equipment). The WES Environmental Assessment Group (EAG) developed a two-stage plan to identify techniques and equipment for the latter assessment. The first stage was to collect data on specific biological, chemical, and physical parameters in the habitats where Eurasian watermilfoil (*Myriophyllum spicatum* L.) (hereafter called "milfoil") was established and attempt to correlate quantitative data on the levels of the various parameters to the biomass of milfoil in the habitats. If relationships between the parameters and milfoil biomass could be demonstrated, then EAG hypothesized that both the potential habitats (i.e. the future distribution) and the potential biomass of milfoil in those habitats could be predicted based on field measurements of the important parameters. The second stage of work would be to field test the hypothesis in a CE District where milfoil was recently established.

Information on existing and potential distribution and existing and potential biomass can be used by CE Districts to determine the problem potential of recently established milfoil populations and to estimate the costs/benefits of an aquatic plant management program for milfoil control. A milfoil population established in "poor" habitat may never develop a maximum biomass that adversely affects users of that habitat but is a source of reproductive material (fragments) that can be carried by water to a "good" habitat within the same or a contiguous water body. The eventual problem potential of an initial milfoil population in a water body is the historical probability that all potential habitats

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

will contain milfoil populations and the potential biomass of milfoil in any of the habitats will depend upon the environmental conditions in those habitats. If the potential habitats and potential biomass can be predicted, then the costs of an immediate management program to control an existing milfoil population can be compared to the costs of controlling milfoil in the future potential habitats, and the benefits to water body users of controlling the existing milfoil population can be compared to the adverse affects the future potential milfoil biomass will have on water body users. If a water body has few potential habitats or the potential habitats will not support a maximum milfoil biomass that will impact users, then milfoil control need not be considered. An additional benefit of the capability to identify potential habitat is that costly field surveys for newly established milfoil populations can be limited to the potential habitat areas.

In 1979, the EAG compiled a list of environmental parameters that were postulated to be important to milfoil establishment and growth, reviewed available literature, and abstracted quantitative data on the parameters. Maximum and minimum values for parameters that were field sampled in or near milfoil populations in a variety of geographic locations were recorded. No literature-reported data were found for several of the parameters that EAG had listed. Consequently, in order to evaluate the importance of the parameters to milfoil establishment and growth, additional field data collection was necessary. A field data collection plan was developed and implemented in conjunction with EAG's studies on preventing the spread of milfoil in the State of Washington (Lazor and Dardeau 1980).* These studies were conducted in Lake Osoyoos, a 5729-acre natural lake in the Okanogan River on the United States-Canadian border in Okanogan County, Washington.

This paper presents a general description of the equipment and techniques used to locate milfoil populations and sample water quality, hydrologic, and sediment parameters for the APCRP work. A unique adaptation of existing instrumentation technology, the AGNAV guidance system, is discussed in detail. A WES technical report is scheduled for publication in September 1981 on all component equipment and techniques used.

Floating Aquatic Characterization System (FACS)

The basic equipment necessary for the APCRP studies has been assembled into a single system, FACS, for characterizing aquatic plant habitats. The components of the system and their applications are

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* Lazor, R. L., and Dardeau, E. A., Jr. 1980. "Large-Scale Operations Management Test to Evaluate Prevention Methodology; Prevention as an Aquatic Plant Management Method," Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Okla., Miscellaneous Paper A-80-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

presented in Table 1. The basic FACS system consists of a pontoon boat equipped with a hydraulically operated submerged aquatic plant biomass sampling head (the biomass sampler), a radio frequency transmitter/receiver (the AGNAV guidance system), a TI-59 programmable calculator with a TI PC-100 thermal printer and direct current (DC) to alternating current (AC) inverter, a Raytheon DE-719B fathometer, and several independent hydrologic sampling systems for water quality, sediment, and meteorological sampling. In addition, computer hardware and software have been assembled for data transformation, analysis, and display. The meteorological station is normally placed on the shoreline of the water body; the individual water quality, hydrologic, and sediment sampling systems are operated from the biomass sampler and the AGNAV, TI-59, and fathometer systems are operated from an auxiliary small boat. Data recorded on cassette tape or on field records are returned to the laboratory for computer analysis.

AGNAV Guidance System

Basic system

A major problem confronting any researcher working in aquatic systems is how to locate and relocate sampling positions within a water body. Several laser, radio frequency, and microwave systems have been developed for military and civilian navigational and positioning use, but their suitability for APCRP use was judged to be too expensive, too bulky, unsafe, or not accurate enough for use in the small boats required for aquatic sampling in the shallow waters of lakes and rivers where aquatic plants are found. In 1979, EAG personnel discussed this problem with British Columbian aquatic plant management personnel who suggested the use of an AGNAV guidance system that they had successfully used to position aquatic herbicide application boats on a transect line for milfoil control.

The AGNAV guidance system is designed for terrestrial agricultural users who want to apply pesticides or fertilizers in straight, parallel, and evenly spaced paths on a field using conventional tractor- or truck-mounted application equipment. As conventionally marketed, the system was suitable for aquatic herbicide applications but could not be used to position a boat at a single sampling point. In an attempt to remedy the problem, EAG personnel discussed it with the AGNAV design engineer. In their discussion it was learned that field service personnel were equipped with a range reader that displayed the distance in machine units (one machine unit = 9.584 in.) from each of the repeaters to the computer/transmitter/receiver (cmptr/xmtr/rcvr) and the distance between the repeaters. This range reader is used by the field personnel to check the calibration of the AGNAV system after repairs.

In conventional use, the AGNAV's internal computer calculates the position of the cmptr/xmtr/rcvr (the tractor-mounted unit) with respect to the two repeaters (placed at opposite ends of the field) based on the

geometric principle that states "in any triangle, if the locations of two vertices and the lengths of all three sides are known, the location of the third vertex is uniquely determined." The AGNAV system is designed to store the distance between the two repeaters (side 1 of the triangle) and the locations of the two repeaters (vertices 1 and 2); to continuously monitor the distance from the transmitter/receiver to the A repeater (side 2 of the triangle) and to the B repeater (side 3 of the triangle); and to calculate the position of the cmptr/xmtr/rcvr (vertex 3). This position is compared to the users desired position in the field (on a path perpendicular to the baseline, a user-specified distance from repeater B). The calculated distance off the path (in feet) and direction to the desired path is indicated on a direction indicator display unit. The user drives the tractor toward the desired path until the display unit indicates the tractor is on the desired path. The actual distances between the cmptr/xmtr/rcvr and repeaters are not displayed to the user of the conventional system.

It was decided that, with a few modifications, the AGNAV system with the range reader and a TI programmable calculator mounted in a small boat could be used to calculate the position of a sampling point based upon the same geometric principle.

<u>Modified system</u>

The modified AGNAV system (Figure 1) consists of a mobile unit and

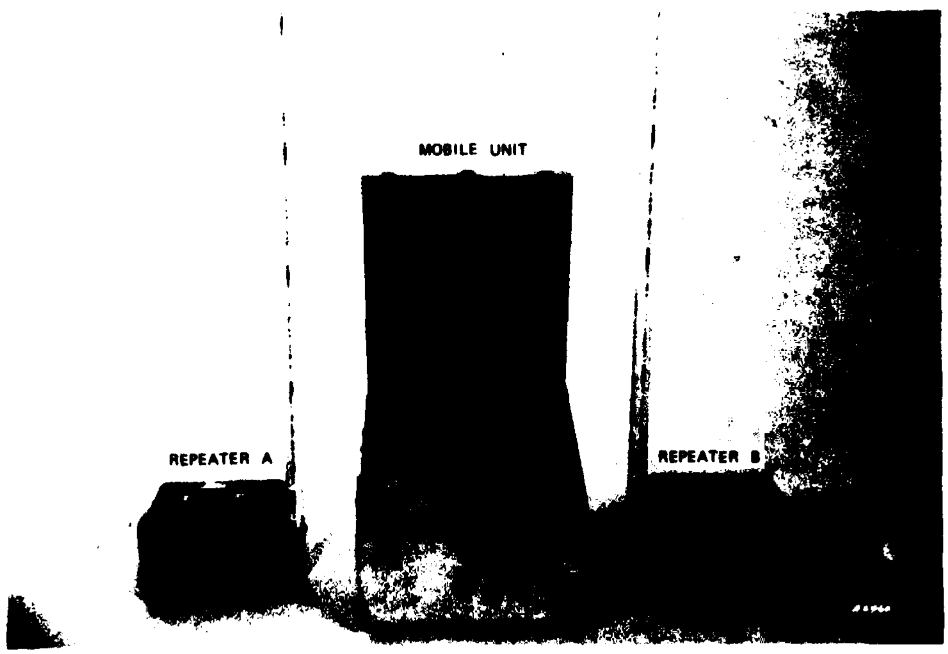

Figure 1. Modified AGNAV guidance system

the two repeaters used with a calculator unit. The mobile unit (Figure 2) is a plywood box with a hinged cover that contains a small 12-v motorcycle battery (auxiliary power), the cmptr/xmtr/rcvr, the control unit, the display unit, and the range reader mounted on an aluminum plate (for grounding); an antenna is mounted outside the box (which is grounded to the plate). The box is 2 ft × 2 ft × 18 in. high, weighs 35 lb, and is one man portable. The calculator unit (Figure 3) is a plywood box (2 ft × 18 in. × 12 in. high, weighs 10 lb) with a hinged cover that contains the TI-59 programmable calculator mounted on the TI PC-100 thermal printer and the 12-v DC to 120-v AC inverter. Power for both the mobile and calculator units is supplied by separate 12-v rechargeable marine storage batteries when the units are in the boat. The power cables to the mobile unit are fitted with a diode that allows both the motorcycle battery and the marine battery to be connected at the same time with 12-v power being drawn from only the storage battery. If the mobile unit must be operated outside the boat, the storage battery can be disconnected and the auxiliary battery will supply the power without loss of power during the switch. Power must be continuously supplied to the mobile unit or it will not give accurate distance readings.

Delineation of sample sites

Aerial photographic and onsite surveys were conducted in 1979 in Lake Osoyoos to identify existing milfoil populations. An onsite survey

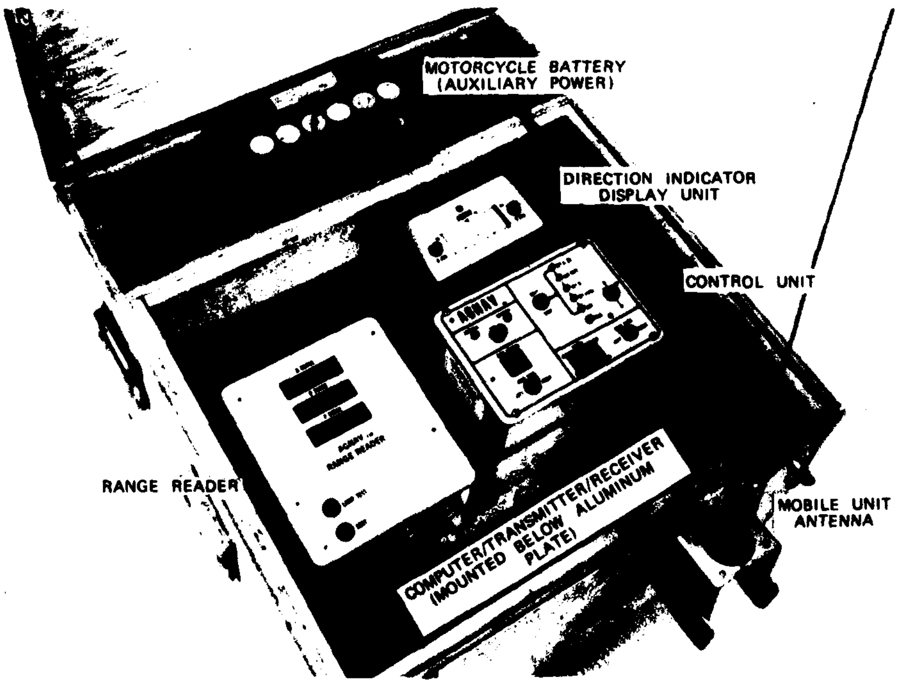

Figure 2. Mobile unit of modified AGNAV guidance system

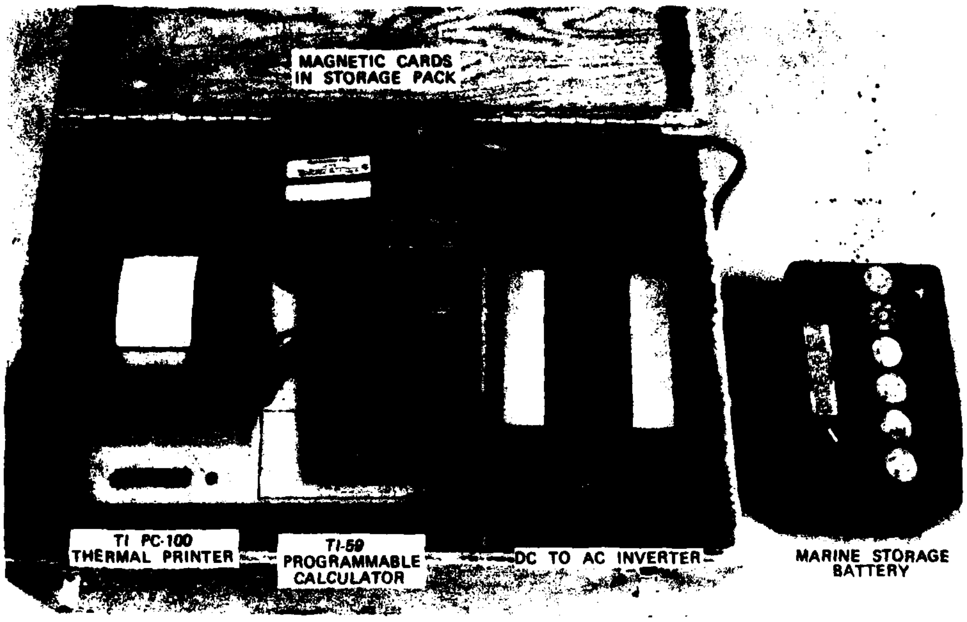

Figure 3. Calculator unit used with AGNAV guidance *system*

in May 1980 was conducted to verify milfoil distribution and select milfoil populations for the FY 80 studies. The field procedures used to delineate the sample points within the populations are presented in the following paragraphs. These procedures were used for all sites in the FY 80 studies, including herbicide efficacy and drift studies sponsored by the Seattle District (NPS) and the parameter/milfoil biomass relationship studies sponsored by the APCRP.

Establishing the baseline and shoreline position. At each site, shoreline locations for the AGNAV repeaters were selected (Figure 4). Desirable locations had the following characteristics:

a. No trees, high brush, or terrain that would interfere with radio-waves from the repeaters to the mobile unit when the mobile unit was located over the milfoil population.

b. Open water at least 1 ft deep between the points of land where the repeaters were placed.

c. A dry, high shoreline so that, even if the water level changed between sample dates, the repeaters could be replaced on the original shoreline positions without inundation or wave splash.

d. The entire milfoil population or a major portion of it between the two lines projected toward the lake perpendicular to the shoreline from the repeater locations (maximum of 1/2 mile between repeaters).

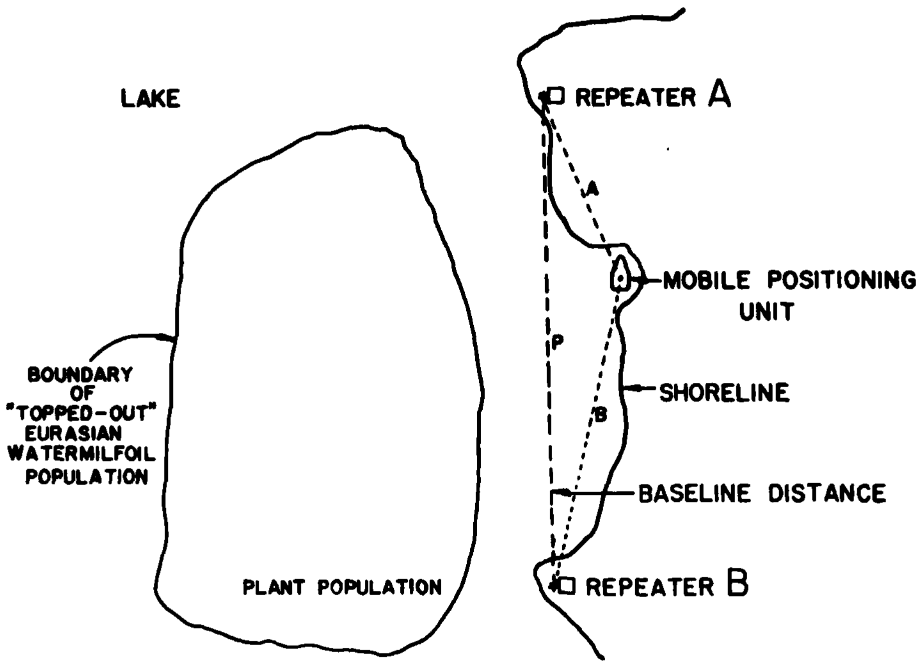

Figure 4. Shoreline locations for the AGNAV repeaters. (A = Distance from repeater A to mobile positioning unit; B = distance from repeater B to mobile positioning unit; P = distance between repeaters.)

Each repeater location was permanently marked with a 12-in. length of 1/2-in. rebar driven flush with the ground and a temporary wooden stake (15 in. long, 1 × 2 in.). The small boat containing the mobile unit was positioned 30 ft from repeater A on the line of sight between the antennas of the repeaters and the "Set A" switch was activated. (The computer calculations used by the AGNAV required a 30-ft offset from the repeater A location and the same offset from the repeater B location.) The boat was then driven along the line of sight to a position 30 ft past repeater B the "Set B" switch was activated. This procedure establishes the baseline. At that point, the range reader (Figure 2) light emitting diodes displays the baseline distance P between the two repeaters and the distance A from repeater A to the mobile unit and the distance B from repeater B to the mobile unit in machine units. The mobile unit can be hand carried between repeaters if no open water is present or can be carried on shore to the required 30-ft offset positions if necessary.

The mobile unit can then be moved anywhere in the lake to a maximum distance of 1 mile from the repeaters. The distance from the mobile unit to repeaters A and B is automatically monitored and updated (100 times/second) and shown on the LED displays labeled "A" and "B,"

respectively. The fixed baseline distance is shown on the LED displays labeled "P." To establish the shoreline position with respect to the repeaters, the boat is driven along the shore and the displayed A and B distances are manually recorded in a field notebook. Repeater locations are also recorded.

Delineation of the boundary of the milfoil population. If the milfoil has "topped-out" (reached the surface), the boat is driven along the boundary of the milfoil and the displayed A and B distances are manually recorded in a field notebook (Figure 5). If the milfoil is below the surface and cannot be seen due to turbidity or depth, transects across the milfoil population are made with a fathometer (Figure 6). The boundaries of the population are marked with tethered floats (lead anchor with nylon rope to surface and styrofoam float); the boat is driven around the floats; and the displayed A and B distances are recorded in a field notebook. Changes in the areal extent of either the topped out or submerged milfoil population suspected on subsequent sample dates are documented using the same procedures based on repositioning of the repeaters on the original repeater locations.

Establishing 1-acre treatment plots. A TI-59 calculator program was developed to calculate the area of a rectangle (in square feet) and the location (in AGNAV machine units) of the four corners if the locations (in AGNAV machine units) of two diagonal corners are known (Figure 7).* This capability was used to establish 1-acre (the program is limited to a maximum of 320 acres) treatment plots for the FY 80 herbicide efficacy and drift studies in Lake Osoyoos (Figure 4). The rectangle must be within an area bounded by the baseline, the two lines projected toward the lake perpendicular to the baseline from the repeater locations, and a line parallel and within 1 mile of the baseline.

To initially establish the corners of a treatment plot, the baseline, shoreline, and boundary of the milfoil population are established as discussed earlier. A beginning corner P_1 of the rectangle is selected (within the milfoil population and near repeater B), marked with a float, and the A and B distances (A_1 and B_1 , respectively) from the corner to the repeaters are manually recorded. A location P_2 for the diagonally opposite corner is selected, marked with a float, and the A and B distances (A_2 and B_2 , respectively) from that corner to the repeaters are manually recorded. The TI-59 calculator, PC-100 thermal printer, and inverter are turned on and the magnetic cards containing the program are read into the calculator. The A_1 , B_1 , A_2 , and B_2 distances are keyed into the calculator and the operator selects the desired output, the area of the enclosed rectangle, which is printed on the thermal paper. If the enclosed area is less than an acre, the float is retrieved, the boat is moved lakeward to a new position, a float is dropped, the new A_2 B_2 distances are keyed into the calculator, and

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* Magnetic cards, readable on a TI-59 programmable calculator, with all programs discussed in this paper and instructions for their use are available from the coauthor of this paper, Bailey.

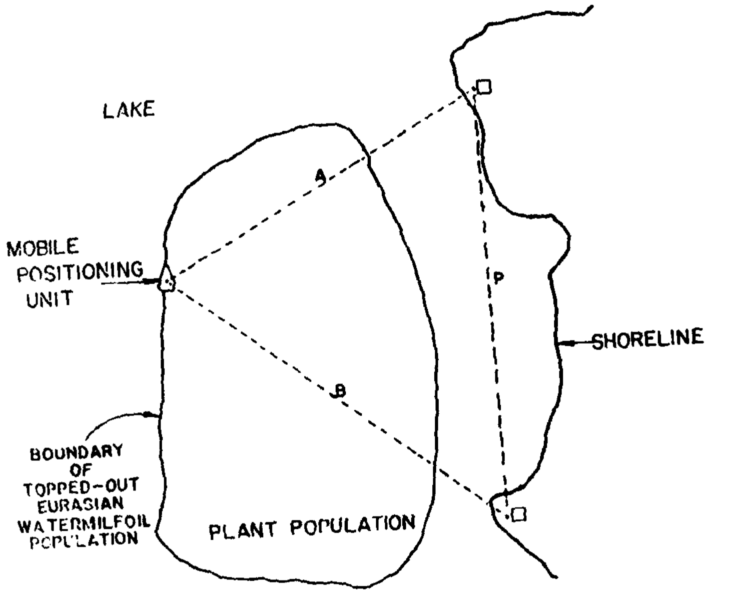

Figure 5. Delineation of the boundary of topped-out Eurasian watermilfoil populations

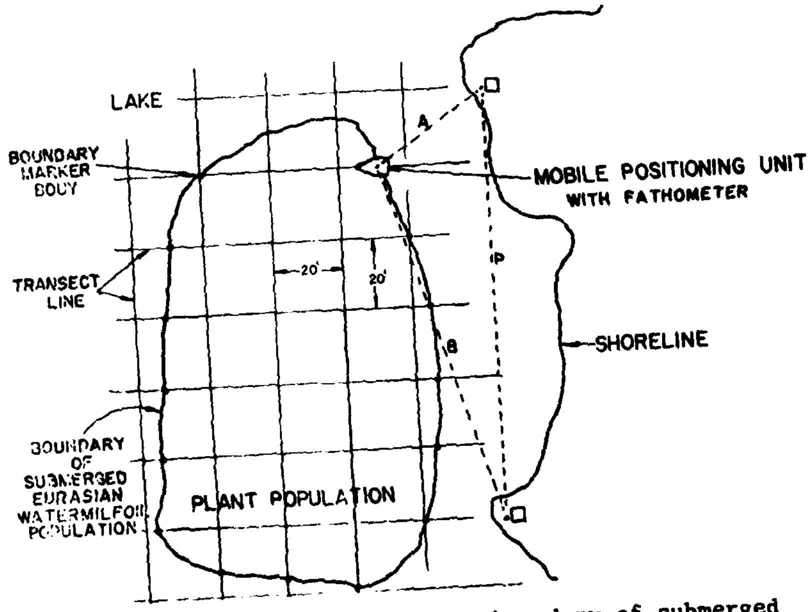

Figure 6. Delineation of the boundary of submerged watermilfoil populations

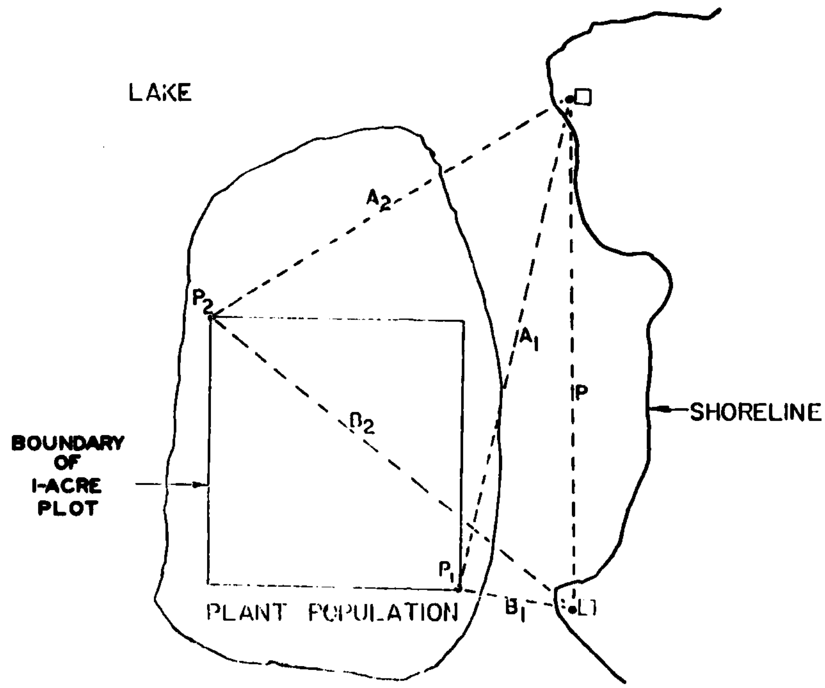

Figure 7. Establishing 1-acre treatment plots

the enlarged area is calculated. If the enlarged area is the desired 1 acre in size, the operator selects the second optional output, the locations of the other two corners (which are printed on the thermal paper), drives the boat toward the third corner by monitoring the range reader displays until the actual A and B distances match the calculated A and B distances, and drops a float; the same is done for the fourth corner.

With experience, ten 1-acre plots, 0.5 mile apart can be established in 5 hr. Relocation of the ten plots, on subsequent sampling dates (which requires only the establishment of the baseline and dropping floats at the previously recorded A and B distances for each corner), can be accomplished in 2 hr.

Establishing sample points for a random sampling approach. The EAG has developed both a random sampling and a systematic sampling approach to selection of sampling points within a 1-acre treatment plot for the APCRP and NPS studies. If the milfoil population within the plot appears to be uniformly distributed (which would suggest uniform sediment and water quality conditions), a random sampling approach could be used. If the milfoil population appears to be nonuniformly distributed (i.e. clumped), then a systematic sampling approach could be used. The flexibility to select either approach can be severely limited by manpower and fiscal constraints for the study. No milfoil population

surveyed in Lake Osoyoos appeared to be uniformly distributed; however, verification of the procedures developed for a random sampling approach was one objective of the FY 80 field studies.

The procedures developed for a random sampling approach involve the use of TI-59 calculator programs that superimpose a 30- × 30-ft grid over the 1-acre plot, number the grid squares beginning at rectangle corner location P_2 , randomly select (via a random number generator) five grids (by number) for sampling, and print the grid number with calculated A and B distances from the center of the grid to the repeaters on thermal paper (Figure 8). The size of the grid square (in feet) can be varied by the operator. Additional grid center sample points in groups of five can be generated by the program. The A and B distances for a specified grid center can be requested.

Establishing sample points for systematic sampling approach. The selection of a systematic sampling approach for the NPS/APCRP studies depended upon the objectives of the study and the variation in topography, soils, plant populations, and hydrologic conditions in the sample plots. For the water quality, herbicide residue, and biomass/parameter studies, evenly spaced sample points along a transect were used. The transects (Figure 9) were run parallel to the shoreline for the water quality and herbicide residue studies because the water currents were predominantly parallel to the shoreline (wind driven) and objectives of the studies were to monitor changes in water quality and herbicide residues entering, within, and leaving the treatment control plots. Transects for the biomass/parameter studies were run perpendicular to the shoreline to monitor changes in biomass and sediment nutrients from shallow to deeper water in the lake. The AGNAV positioning system was used to establish the transect routes and sampling points along the transect. Sample locations were recorded (A and B distances) in field notebooks so the same points could be relocated on subsequent sampling dates.

For the herbicide efficacy studies, five sample points in the plots in topped-out milfoil populations were selected (Figure 10). Since the milfoil was in a clumped (nonrandom) distribution and the objectives were to monitor biomass reduction using conventional herbicides at reduced rates, it was not necessary or possible (due to manpower and fiscal constraints) to determine plot average biomass (which would have required considerably more samples/plot).

Data entry, retrieval, analysis, and display. Raw water quality and meterological data from the field (stored on cassette tapes) were automatically transcripted to computer compatible cassette tapes using the Martek data reader, computer interface, and TI-700 ASR terminal (Figure 11). The field-recorded data and results of laboratory analyses of sediment nutrients, biomass, and herbicide residues were manually entered onto computer magnetic tapes. The TI-700 ASR terminal was then used to edit and transfer all data to the Honeywell GE-635 computer magnetic tapes. Analysis of these data has not been completed.

The Tektronix 4014-1 terminal and 4662 and 4663 interactive digital plotters were used to provide display and hard copy graphics of

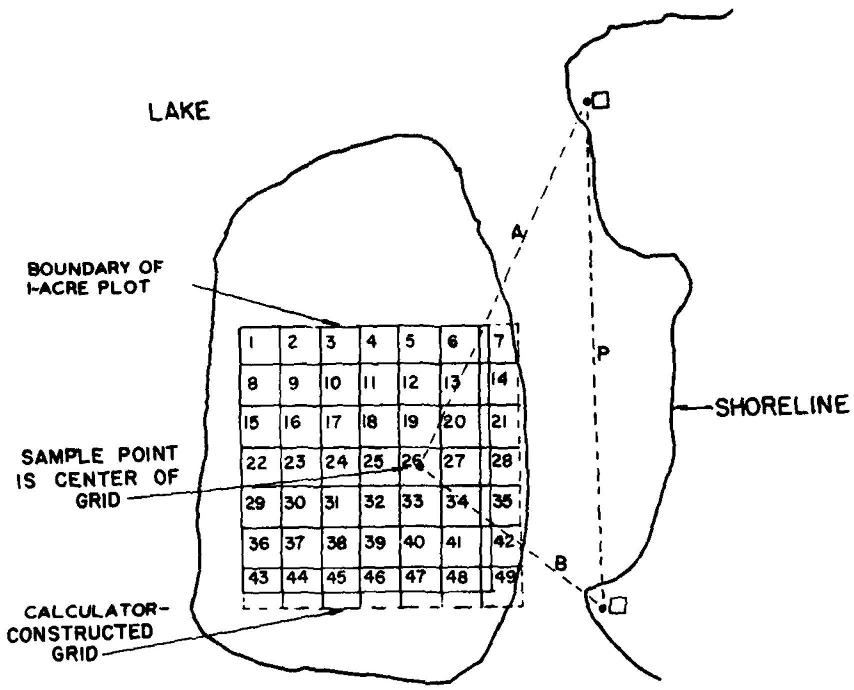

Figure 8. Establishing sampling points for the random sampling approach

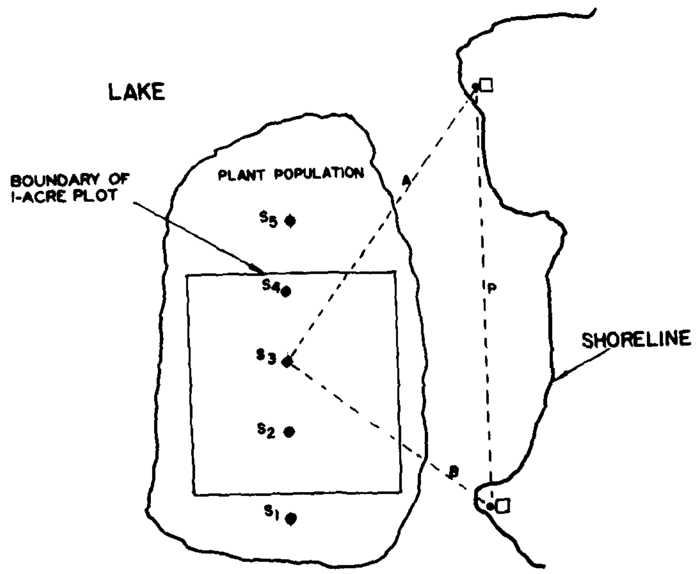

Figure 9. Establishing sampling points for the systematic (transect) sampling approach for the water quality, herbicide residue, and biomass/parameter studies

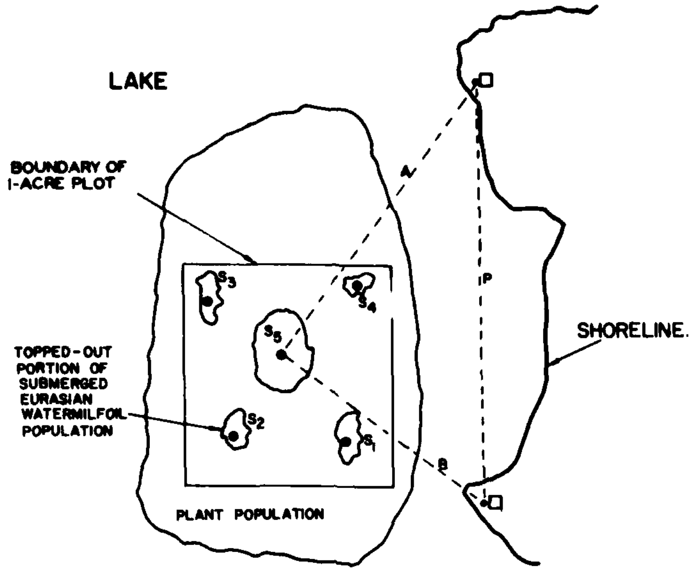

Figure 10. Establishing sampling points for the systematic sampling approach for the herbicide efficacy studies

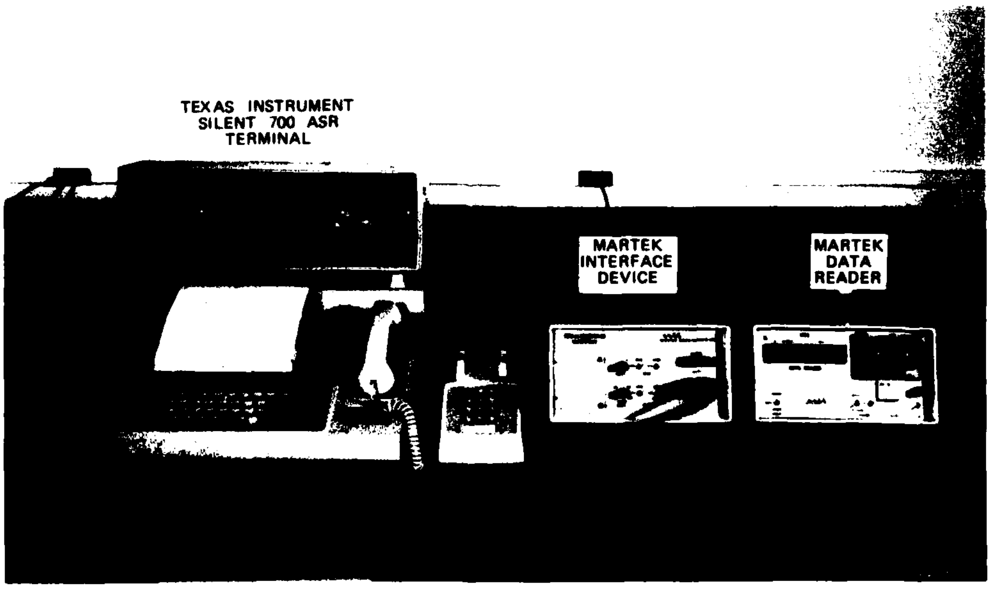

Figure 11. Equipment used to transform raw field data stored on cassette tapes to computer-compatible cassette tapes

the study areas (Figure 12). The AGNAV A and B distances for all sample points, plots, shoreline, and milfoil population locations are entered into a computer file. A program was developed to retrieve the data and display the locations of the sample points with respect to the shoreline, plot, and milfoil population (Figure 13). Hard copy graphics of the study are drawn to various scales depending upon the use of the graphics.

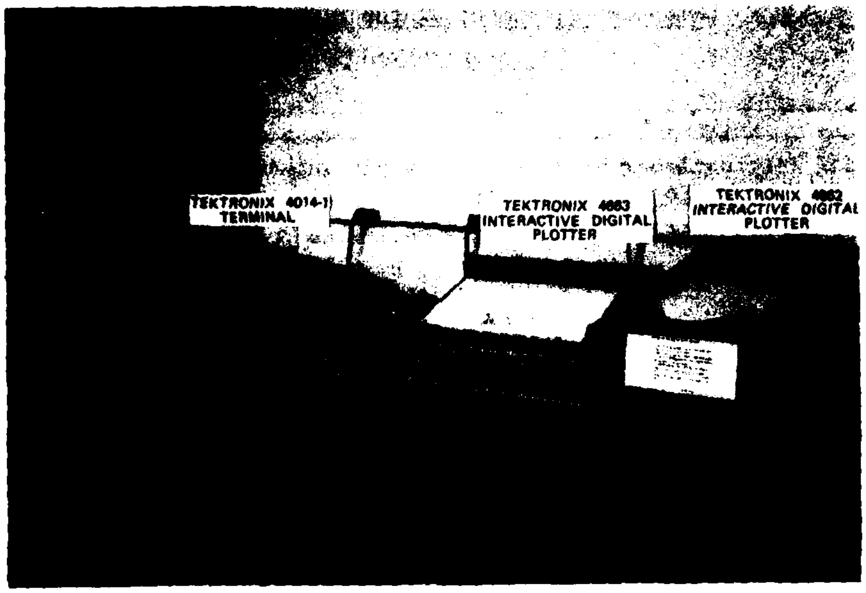

Figure 12. Equipment used to prepare display and hard copy graphics of study areas

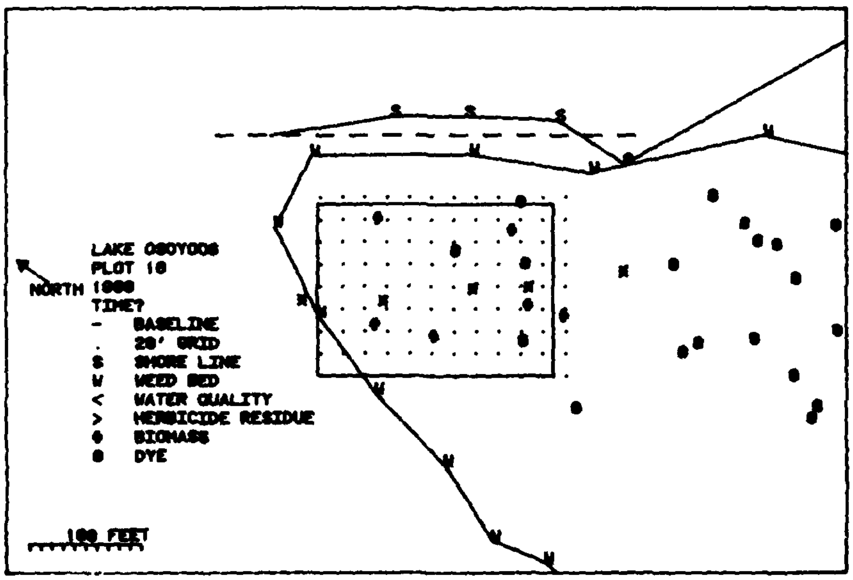

Figure 13. Hard copy display of plot 16 in Lake Osoyoos

Table 1

Component Equipment of the Floating Aquatic Characterization System

Component	Application
Aquatics International biomass sampler mounted on pontoon boat	Sample submerged aquatic plant biomass
AGNAV guidance system	Determine position of plant populations and sample points with respect to shoreline
Texas Instruments TI-59 programmable calculator	Calculate area of sample plots, location of plot corners, location of random sampling points, and location of grid centers
Raytheon DE-719B fathometer	Determine water depth and height of submerged aquatic populations
Martek Mark V digital water quality analyzer with data logger, data reader, and computer interface	Sample dissolved oxygen, pH, conductivity, and water temperature; record data; read data; convert data to computer-readable form
Masterflex sampling pump with teflon tubing	Collect water samples for herbicide residue analyses
Marsh-McBirney Model 201 portable water current meter	Determine water velocity
WILDCO K B core sampler	Collect sediment samples for herbicide residue, soil type, and nutrient analyses
Turner Designs flourometer	Determine horizontal and vertical dispersion of dye in water
LiCor quantum radiometer photometer	Determine level of photosynthetically active solar radiation underwater
Meterological station with Martek data logger	Collect data on wind speed and direction; record data on cassette tape
Texas Instruments Silent 700 ASR terminal with data cassettes	Transmit data from Martek computer interface to GE-635 computer; edit raw field data; store data on cassette tape
Tektronix 4014-1 terminal, Tektronix 4662 interactive digital plotter, and Tektronix 4663 interactive digital plotter	Data manipulation, entry and retrieval, graphics display and editing, hard copy graphics
Honeywell GE-635 computer	Data analysis and storage

GENERAL STUDIES

Recording Fathometer for Hydrilla Surveys

by

Jerome V. Shireman* and Michael J. Maceina*

Introduction

Aquatic macrophytes are an integral component of freshwater ecosystems; however, excessive amounts of vegetation can alter fish populations, limit recreational use, create health hazards, and block navigational and irrigation routes (Blackburn 1975). The introduced submersed macrophyte, hydrilla (*Hydrilla verticillata*), exists throughout 250,000 ha of Florida's water and is reported in nine other states including California (Shireman and Haller 1979). In order to evaluate various hydrilla control methods, quantitative data pertaining to the distribution and biomass of the plant must be obtained.

The purpose of this research project was to continue to monitor hydrilla abundance-white amur interactions in Lake Baldwin and refine previously tested fathometer techniques for determining distribution and biomass of hydrilla in two additional Florida lakes (Lake Pearl and Orange Lake).

Materials and Methods

A DE-719 Precision Survey Fathometer (Raytheon Marine Co., Manchestor, N. H.) was utilized for all vegetation surveys. Procedures for conducting transects and determining quantitative vegetation parameters were followed according to the methods of Maceina and Shireman (1980). In Lake Baldwin, 14 transects totaling 11.32 km in distance were conducted quarterly starting in June 1979. Thirteen transects covering 12.96 km in distance were conducted on Orange Lake in January and June 1980. Due to extensive surface matting, transects on Orange Lake were successfully conducted in an airboat. A bracket was mounted to the transom of the airboat to house the transducer. In Lake Pearl, 12 transects, 3.55 km in distance, were completed in March, May, and June 1980.

Attempts were made in Lake Pearl and Orange Lake to correlate and develop regression models predicting hydrilla biomass by fathometer tracing characteristics. While transects were being conducted on 10 March 1980 in Lake Pearl, numbered buoys were dropped to mark hydrilla

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* Center for Aquatic Weeds, University of Florida, Gainesville, Florida.

biomass sampling stations. Simultaneously, corresponding fix marks were placed on the chart paper and the buoy number was recorded on the paper. The following day, a circular core biomass vegetation sampler was used to take replicate 0.257-m^2 samples at each buoy. Samples collected with the biomass sampler were washed and shaken in a nylon net to remove excess sand, muck, and water and weighed to the nearest 5 g. Wet weights were later converted to kilograms per square metre for analysis. A total of 50 samples were taken from 25 stations and collected from water depths ranging from 1.5 to 2.6 m.

Utilizing sampling methods similar to those conducted on Lake Pearl, 32 hydrilla stations were established on two transects in Orange Lake on 19 May 1980. Single biomass samples were taken at each station in water depths ranging from 1.7 to 2.7 m.

White amur were captured utilizing direct current pulse electroshock fishing gear, monofilament gill nets, rotenone, and a modified gill net-seine in Lake Baldwin. Fish were measured, in millimetres, for total length (TL) and were weighed to the nearest 0.05 kg.

Individual white amur growth data from Lake Baldwin were not available. Mean weight and TL of white amur stocked during 1978 were calculated to be 0.79 kg and 408 mm, respectively. Of the 2123 white amur estimated to be in Lake Baldwin by November 1978, 13 percent of the population was left from stockings make in 1975. Growth data were generated by regression techniques based on the mean stocking size and time. Thirteen percent of the largest fish were eliminated from the analysis. Growth of the white amur was rapid during the first 2 years of stocking, with fish obtaining a mean weight of 9.17 kg by July 1980 (Table 1). Growth apparently was not as rapid during the second year of introduction.

Calculated Hydrilla Consumption by Large White Amur

Information pertaining to the consumption rates of large white amur (>1 kg) on hydrilla is nonexistent. Small white amur (<300 mm TL) are known to consume their own body weight in vegetation per day. Utilizing standing crop estimates from fathometer calculations and white amur capture data, consumption rates were determined for Lake Baldwin large white amur (Table 2). The following assumptions were made: (1) hydrilla did not grow during the period from September 1979 to March 1980, although some winter dieback could have occurred; (2) nearly 100 percent white amur survival occurred following stocking; (3) white amur recovered during the sample periods reflected the true mean weight of all fish in the lake, including pre-1978 fish; and (4) standing crop estimates taken with the fathometer were accurate. Calculations showed that large white amur (>6 kg) consume 26 to 28 percent of their body weight in hydrilla. Gut contents of white amur taken from Lake Baldwin during September and December 1979 contained hydrilla that accounted for 8 to 10 percent of the total body weight. Exact 24-hr digestive rates, however, are not known for large white amur. Large white amur (>6 kg) probably exhibit

consumption rates between 10 and 20 percent of the body weight per day during optimal feeding conditions.

Hydrilla Control by White Amur in Lake Baldwin

Hydrilla control was evident by April 1979 when large areas were devoid of vegetation. Following the 1978-1979 winter dieback, hydrilla standing crop increased slightly during the summer of 1979. White amur standing crop was estimated to be 10,000 kg in April 1979 when hydrilla control was evident (Figure 1). Therefore, effective control was

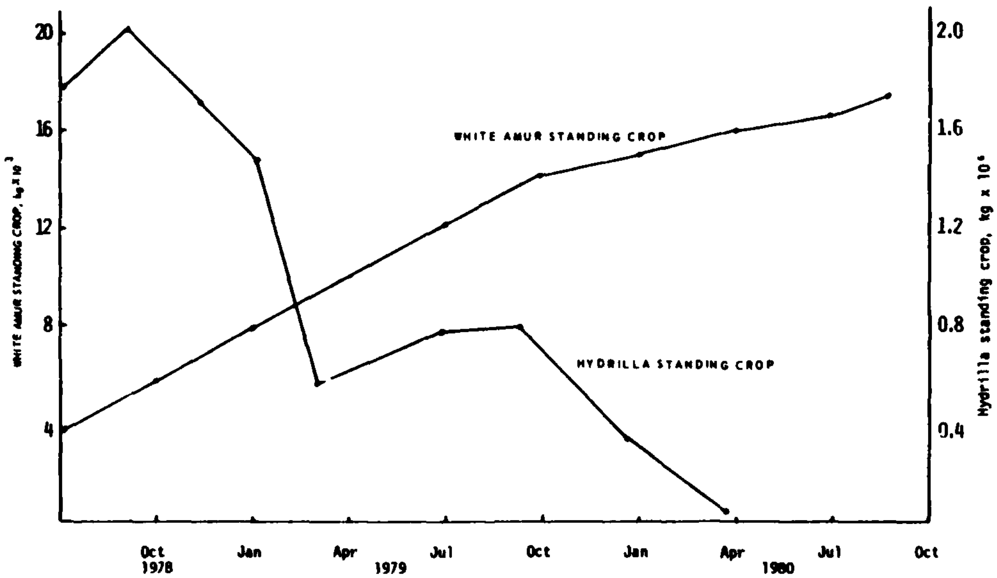

Figure 1. White amur and hydrilla standing crop in Lake Baldwin, Florida, October 1979 through October 1980

obtained with 185 kg of fish per hectare of hydrilla in Lake Baldwin. A decrease in light penetration due to a phytoplankton bloom probably aided by shading hydrilla in water depths greater than 4 m during the summer of 1979. Hydrilla could not be found in the lake after March 1980.

Volume of Hydrilla

The volume of hydrilla infesting a water body was derived utilizing a hypsographic curve, which is a plot of mean hydrilla height and area infestation by depth intervals. Mean hydrilla height values were plotted

on hypsographic volume curves at the mean depth calculated for each depth interval. The percentage of depth interval areas infested with hydrilla was considered and incorporated in each hypsographic figure. A line was drawn connecting the points designating the top of the hydrilla plants along the depth intervals. The enclosed area from the top of the plants to the lake bottom represented the volume of hydrilla in the lake. This volume was calculated by planimetry, and the percentage of the lake volume infested with hydrilla was derived by dividing hydrilla volume by lake volume.

The total water volume of Lake Baldwin was calculated to be 344.5 ha-m. The hydrilla volume in the lake declined from 106.9 ha-m to 69.8 ha-m or from 31 to 21 percent of the total lake volume between June 1978 and June 1979. Total percent cover or the area of the lake infested with hydrilla did not decline, but increased from 62 to 69 percent during the same period. The discrepancy between the two measurements was caused by a decrease in hydrilla height, especially in water depths greater than 4 m. Therefore, decreased plant height caused a decrease in hydrilla volume. The total volume of hydrilla in a lake is a better descriptive quantitative parameter than percent cover because area coverage (hectares) as well as vertical coverage is considered. The percentage of the total water volume in Lake Baldwin infested with hydrilla increased from 31 percent in June to 41 percent by November 1978, then declined during 1979 (Table 3). Winter dieback and white amur consumption of hydrilla caused the decline in 1979.

Interrelationship Between Total Percent Cover, Hydrilla Volume, and Standing Crop

Transect percent cover and total percent cover data indicated that peak biomass occurred in November 1978 and January 1979. Total hydrilla standing crop, hydrilla height, and hydrilla-surface data also indicated that peak biomass occurred in November 1978 and January 1979. Total hydrilla standing crop, hydrilla height, and hydrilla-surface data indicated that peak abundance occurred in November 1978.

The increase in total percent cover during November 1978 and January 1979 was due to the expansion of "sparse hydrilla" into the 6.0- to 6.9-m depth strata after August 1978. However, hydrilla growing at this depth interval contributed less than 5 percent to the total standing crop for November 1978 and January 1979. Although total percent cover was less in August than in November 1978, the maximum standing crop value was obtained in August, which was due to extensive surface matting and peak hydrilla height values. Hydrilla volume calculations were generated from both area infestation and hydrilla height data. The increase in total percent cover from August to November 1978 from 67 to 78 percent caused a slight increase in percent hydrilla volume, from 39 to 41 percent, even though hydrilla height declined in water depths less than 5 m during this time.

Hydrilla volume estimates remained constant (21 percent) in March

and June 1979, but standing crop estimates indicated an increase of 0.2 million kilograms during this time. The fact that hydrilla growth characteristics differ in shallow and deep water might explain these differences. As the plant approaches the water surface, the following occurs: (1) the amount of sunlight reaching hydrilla increases and more nodes are produced on the stem, and (2) the stem tends to grow and extend itself in a horizontal position to capture a greater proportion of the sunlight and thick, entangled, intertwined mats result. These two factors cause an increase in weight per unit volume when hydrilla is growing in shallow water or close to the surface.

Utilizing biomass data collected with a 0.257-m^2 core vegetation sampler, kilograms of hydrilla per cubic metre was calculated by dividing actual biomass by hydrilla height obtained from chart tracings. For example, if actual biomass equaled 2 kg/m^2 and chart tracings indicated that hydrilla height was 2 m, the hydrilla weight per unit volume would equal 1.00 kg/m^3. Hydrilla weight per unit volume of water decreased with increasing water depth from 4.51 kg hydrilla/m^3 in the 1.0- to 1.9-m water depth to 0.06 kg hydrilla/m^3 in the 6.0- to 6.9-m water depth (Table 4). From March to June 1979, a dramatic decrease in hydrilla height occurred in water depths greater than 4 m. Thus, the major portion of hydrilla volume was located in shallow water. Actual hydrilla weight volume data indicated a greater standing crop of hydrilla existed in shallow water than deep water on a volume basis. Therefore, standing crop estimates were different from volume estimates due to greater infestations in shallow water.

In analyzing results and changes in hydrilla abundance, the calculation of a variety of quantitative vegetation parameters is recommended.

Hydrilla Biomass-Fathometer Tracing Correlations

Biomass-fathometer data collected from Lake Pearl and Orange Lake in March and May 1980 were analyzed to correlate actual hydrilla biomass with fathometer tracing characteristics. Regression equations were constructed in a similar fashion to those utilized in Lake Baldwin (Maceina and Shireman 1980). Two separate models were employed to predict biomass: (1) "thick hydrilla," indicated by sampling stations where dense hydrilla did not permit a reading of the lake bottom, and (2) "sparse hydrilla," which permitted a clear reading to the bottom. Of the 25 stations, 22 sampled for hydrilla biomass in Lake Pearl were characterized by thick hydrilla. For this reason, sparse hydrilla models were not calculated in Lake Pearl. In Orange Lake, sampling stations were characterized by both sparse and thick hydrilla. Criteria established for selecting best fitting regression equations were maximizations of coefficients of determinations (r^2).

Regression equations predicting hydrilla biomass with tracing characteristics for Lake Pearl and Orange Lake were all significant

($P < 0.05$) (Table 5). However, Orange Lake models displayed much higher correlation coefficients (r) than Pearl models. Correlation coefficients were lower than those calculated from Lake Baldwin. Two factors probably account for this: (1) a greater number of biomass samples were taken in Lake Baldwin, and (2) the difference between the minimum and maximum water depth sampled in Lake Baldwin; therefore, tracing characteristics showing hydrilla abundance were much more homogeneous in these two lakes.

A difference in best fitting regression lines was observed among the three lakes (Table 5). These differences may have been due to the shallower biomass samples taken in Lake Pearl and Orange Lake which altered the statistical relationships that fit the Lake Baldwin mode. Hydrilla densities might be different in these lakes and the tracings obtained with the fathometer are not reflecting these densitites.

Best fitting regression equation formulated for Lake Baldwin did not appear applicable to Lake Pearl and Orange Lake. A negative relationship between hydrilla height (HYDHT) and biomass ($b_1 = -2.797$) existed for the Lake Pearl thick hydrilla model. As hydrilla height increases, biomass also should increase creating a positive slope (Maceina and Shireman 1980). A positive relationship between the distance from the top of the hydrilla plant to the water surface (HYDSUR) and biomass ($b_2 = +1.085$) was noted for the Orange Lake sparse hydrilla model. This also contradicts earlier findings from Lake Baldwin, where a negative relationship existed. As *hydrilla declines* in height from the water surface, biomass should decrease.

The independent variables that best predicted hydrilla biomass in Lake Baldwin were used to calculate Orange Lake sparse and thick hydrilla models (Table 6). Correlation coefficients were slightly less than those observed for the best fitting models calculated for Orange Lake. However, regressions calculating the model sums of squares declined when Lake Baldwin variables were used for Orange Lake data, causing respective F-values to decline and predictions to be less reliable. Intercepts and independent slope coefficients were different from those found in Lake Baldwin. Slope coefficients for hydrilla height and cover were positive in Orange Lake models. A negative relationship for the hydrilla-surface distance was observed in the thick hydrilla similar to the relationship found in Lake Baldwin. A positive slope between hydrilla-surface distance and biomass existed in the Orange Lake sparse model, dissimilar to the Lake Baldwin model.

The best fitting Lake Pearl thick hydrilla model demonstrated that the same independent variables as used in Lake Baldwin were the best variables to predict thick hydrilla biomass in Lake Pearl. The slope coefficients predicting biomass from the log (hydrilla-surface) were similar, 1.320 and -1.301, but the equation intercepts and hydrilla height slope values were different.

In order to analyze model response differences among lakes Baldwin, Orange, and Pearl, the compartments of the thick and sparse hydrilla models were used to form multiple linear regressions. Equations were

calculated by regressing independent variables (HYDHT, COVER, and HYDSUR) against biomass.

For Orange Lake and Lake Baldwin thick hydrilla, hydrilla height slopes were found to be similar ($P > 0.05$; Figure 2); however, intercepts were significantly ($P < 0.01$) different. Similar slopes indicated that a change in hydrilla height produced an equal change in biomass for both lakes. The higher produced an equal change in biomass for both lakes. The higher intercept calculated for Orange Lake indicated hydrilla biomass per unit length of hydrilla height was greater in Orange Lake. The Lake Pearl hydrilla height biomass relationship was not analyzed because a negative and highly insignificant regression slope was calculated. The hydrilla-surface distance predicting biomass in Baldwin, Orange, and Pearl thick hydrilla models demonstrated significant ($P < 0.05$) differences in slope (Figure 3). As shown by the regressions, the hydrilla-surface biomass relationship produced different magnitudes of biomass change in the three lakes, with Orange Lake data producing the steepest slope and Lake Pearl the flattest.

When comparing sparse hydrilla independent variables from Lake Baldwin and Orange Lake, water depths greater than 2.7 m in Baldwin were eliminated from the regression equations. This eliminated the variation caused by deep water hydrilla. Hydrilla-height and hydrilla-surface equations demonstrated equal ($P > 0.05$) positive and negative slopes, respectively, in lakes Baldwin and Orange (Figures 4 and 5). Corresponding intercepts in Lake Baldwin were significantly higher ($P < 0.01$) for both equations than Orange Lake, which indicated greater biomass values in Lake Baldwin. Regressing biomass against percent vertical cover produced slopes where the cover values between the two lakes did not overlap (Figure 6). Cover values for shallow water sparse hydrilla were above 50 percent in Lake Baldwin, while cover values were generally below 50 percent in Orange Lake. Slope analysis, however, revealed a significant ($P < 0.05$) difference in cover slopes between the two lakes.

Data from lakes Baldwin, Orange, and Pearl indicate that independent predictive values of biomass taken with the fathometer did not form similar relationships in each lake. Differences in subsurface light intensity, water chemistry, and substrate types may cause differences in hydrilla growth patterns that are not detectable with the recording fathometer used. Differences in the number of stems per unit area and mean internodal lengths can alter biomass estimates among lakes. Two independent variables predicting hydrilla biomass in these three lakes, hydrilla height and hydrilla-surface distance, do not consider hydrilla density (i.e., hydrilla weight/m^3, number of stems/m^3, $\bar{X}$ internodal length/m^3). These two variables are used in the sparse and thick hydrilla models and these variables do not explain the biomass variation in different hydrilla densities. For the sparse hydrilla model, vertical percent cover may be sensitive to a change in hydrilla density, hence biomass. Orange Lake hydrilla demonstrated lower vertical percent cover values than Lake Baldwin hydrilla; therefore, the corresponding biomass values were lower (Figure 6). The influence of hydrilla height and hydrilla-surface variables, however, might be partially negating

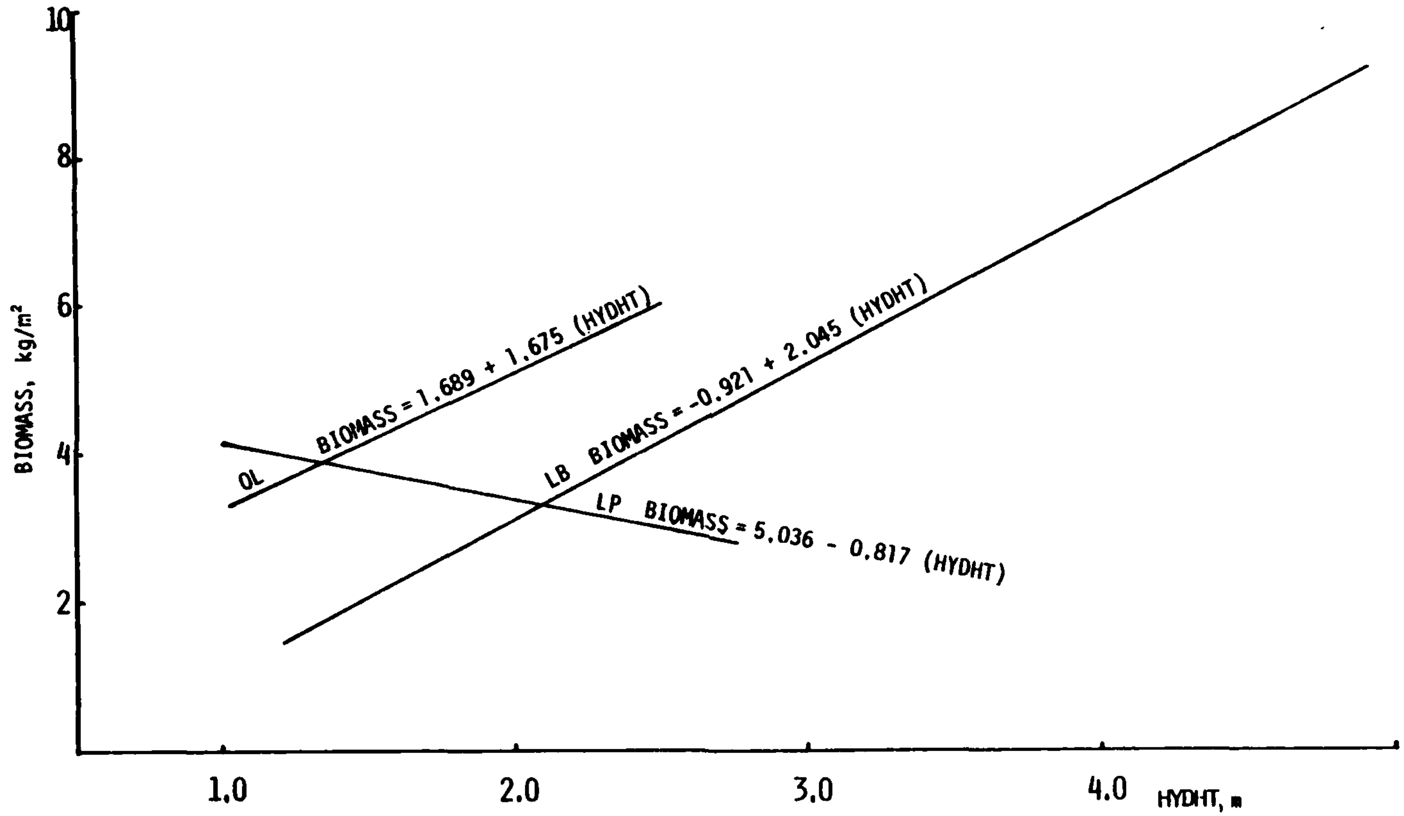

Figure 2. Hydrilla height slopes (thick hydrilla) for Lake Baldwin (LB), Lake Pearl (LP), and Orange Lake (OL), Florida

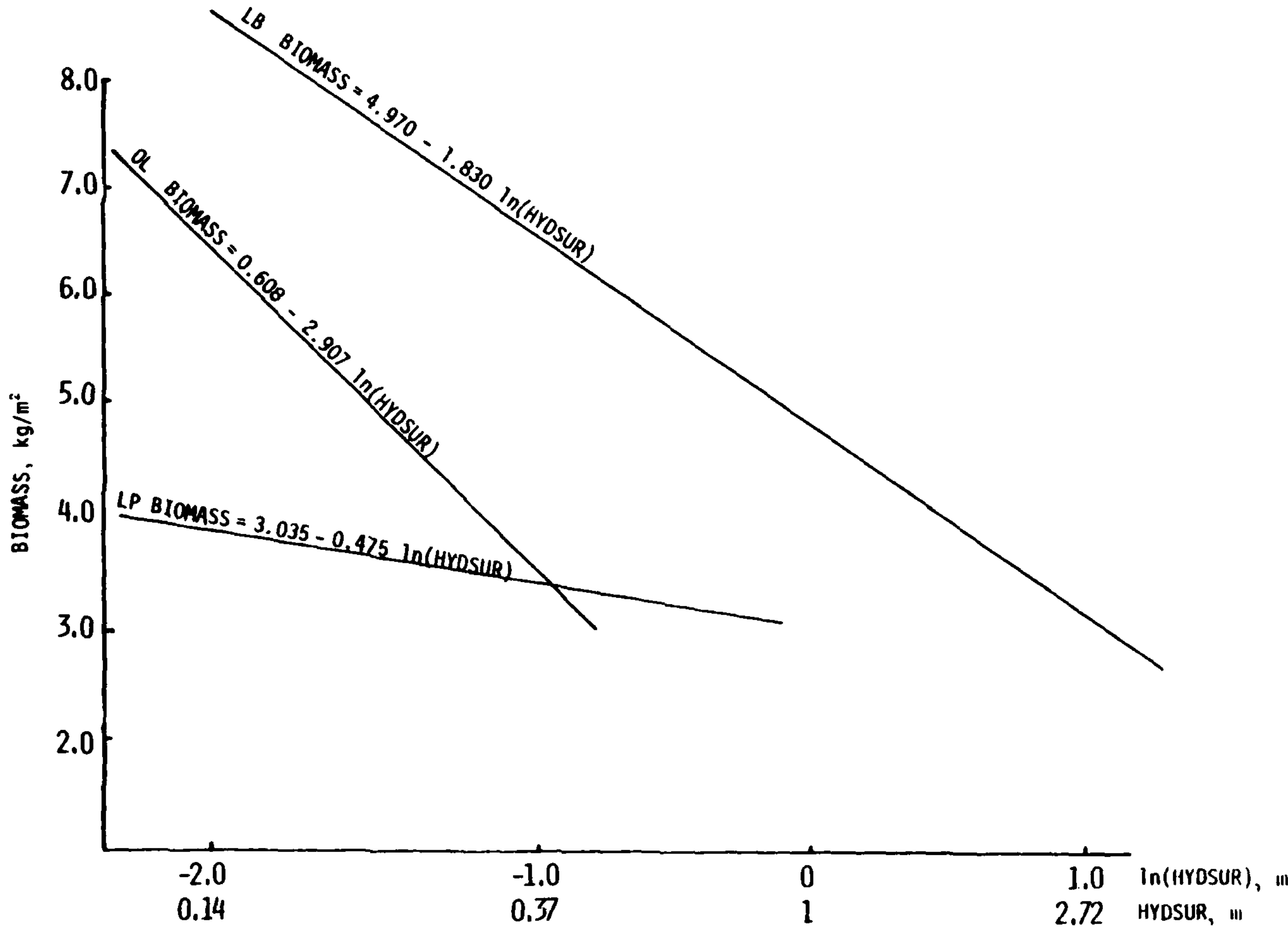

Figure 3. Hydrilla-surface slope relationships for Lake Baldwin (LB), Lake Pearl (LP), and Orange Lake (OL)

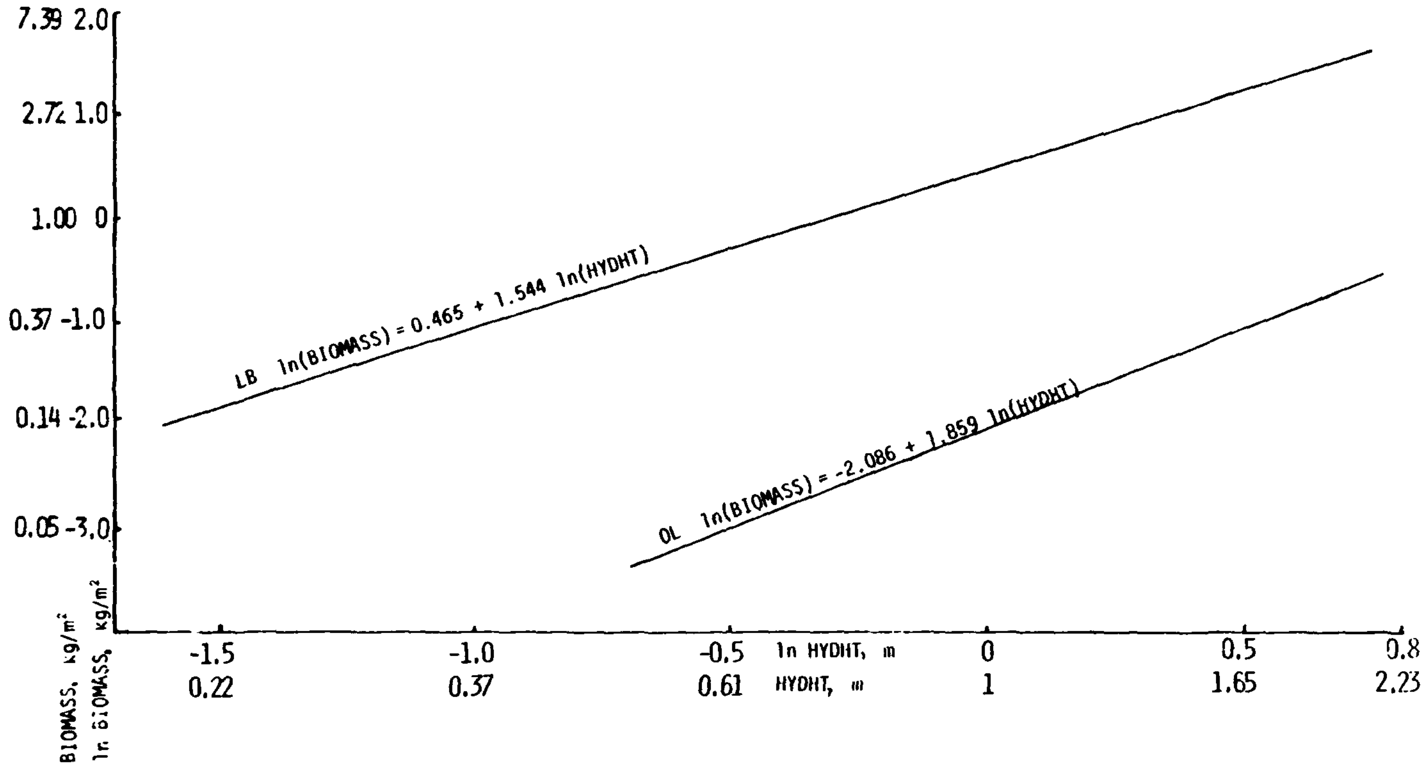

Figure 4. The independent variable HYDHT regressed against biomass illustrating Orange Lake (OL) and Lake Baldwin (LB) sparse hydrilla

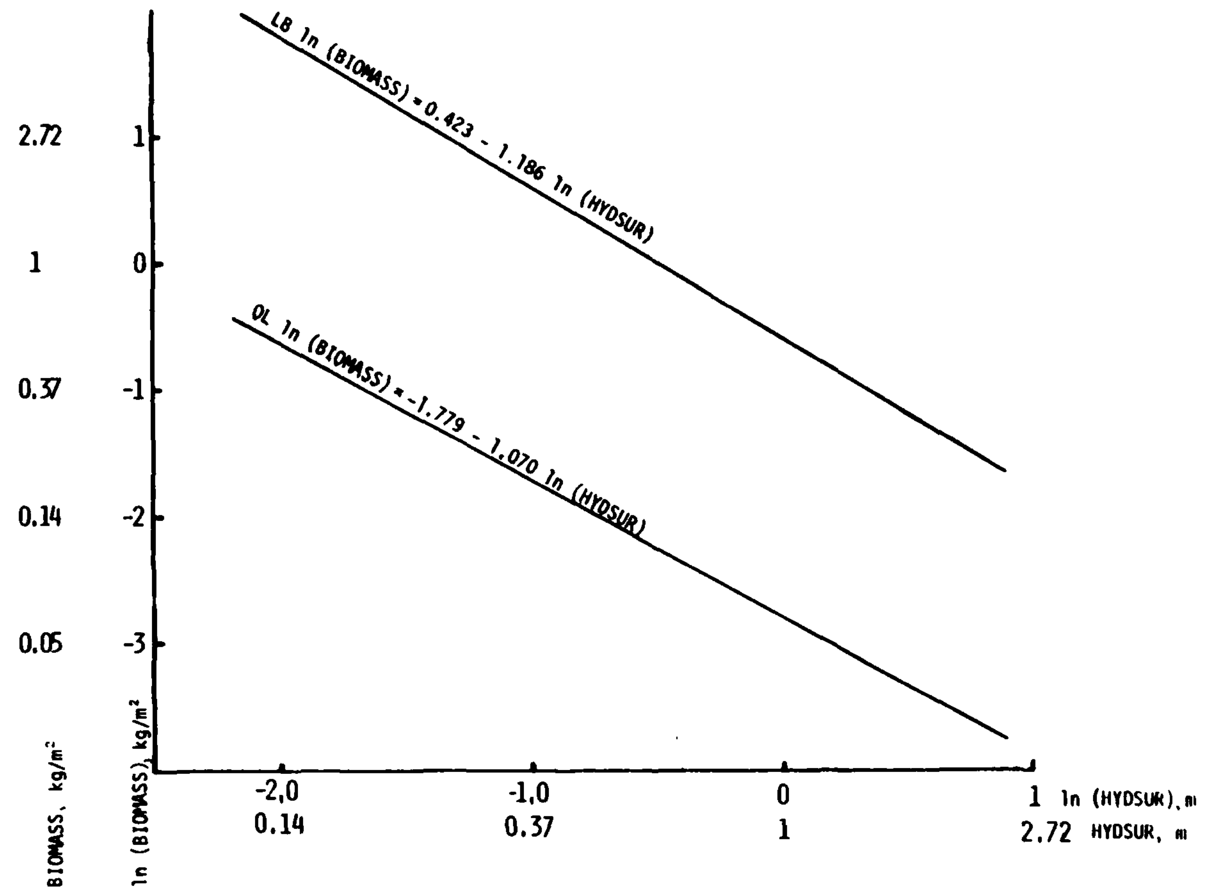

Figure 5. The independent variable HYDSUR regressed against biomass illustrating Orange Lake (OL) and Lake Baldwin (LB) sparse hydrilla

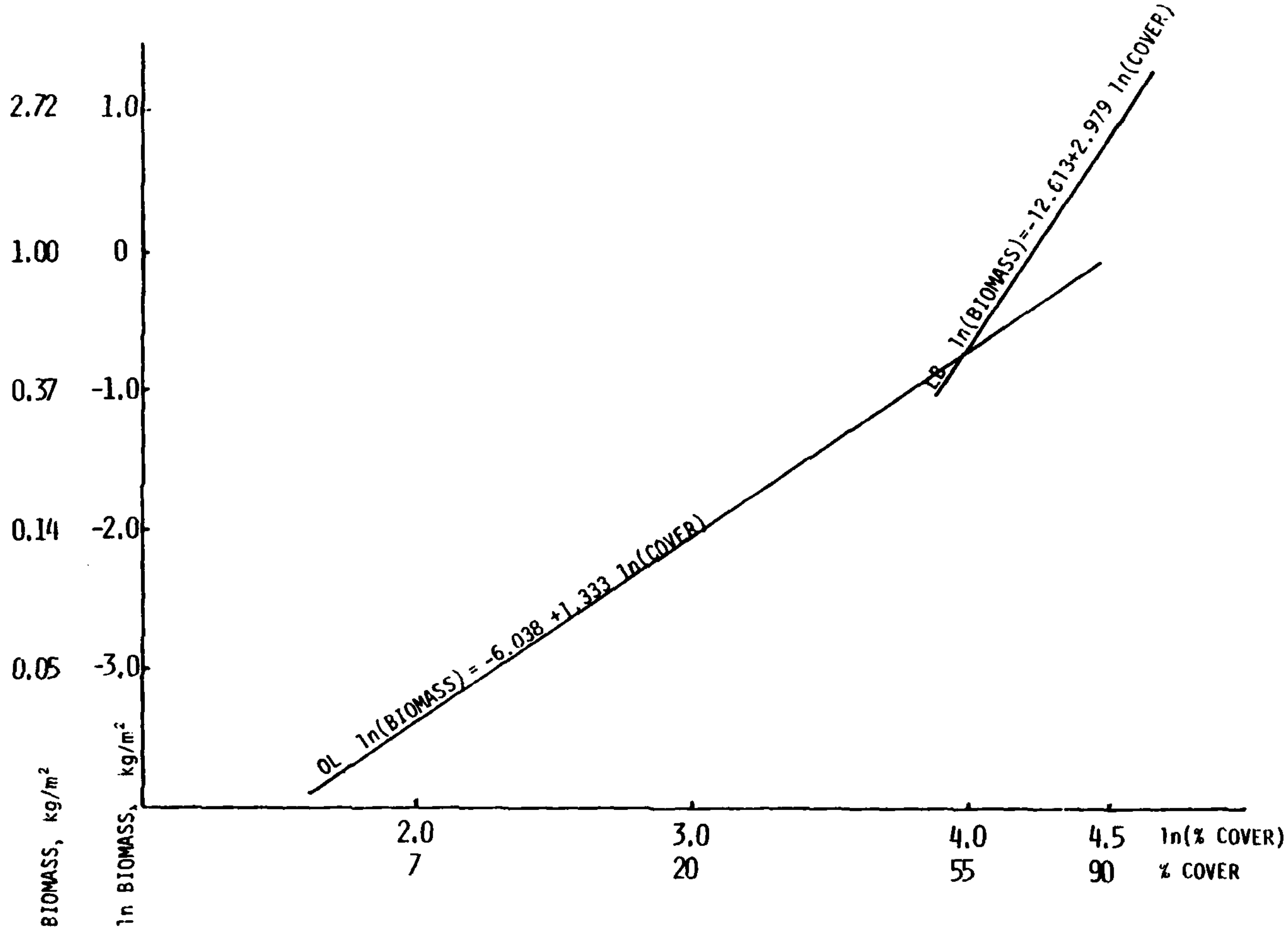

Figure 6. The independent variable COVER regressed against biomass illustrating Orange Lake (OL) and Lake Baldwin (LB) sparse hydrilla

the predictive capability of the cover variable in the Orange Lake multiple regression.

Thick hydrilla models utilized only hydrilla height and hydrilla-surface distance to predict biomass in lakes Baldwin, Orange, and Pearl; therefore, plant density was not considered in this model type. One variable not entered into the current thick models, hydrilla thickness, was analyzed in the three lakes as a measure of hydrilla density. Hydrilla thickness was defined as the distance from the top of the hydrilla plant to the bottom of the visible tracing pattern. Hydrilla was certainly growing below this point down to the hydrosoil, but plant density prevented soundwave transmission. We hoped to find a negative relationship between hydrilla thickness and biomass. As the hydrilla thickness decreased, plant density and biomass should increase. Analysis proved this factor to be insignificant; hence, it was not included in the model.

Utilizing actual biomass data, we have evidence that hydrilla density differences occur between lakes (Table 7). Thick hydrilla growing in 2 to 3 m of water in Lake Baldwin had higher weight:volume values than similar hydrilla in Orange Lake, and was significantly ($P < 0.05$) higher than values obtained from Lake Pearl. The biomass:hydrilla-surface distance relationship between the three lakes clearly shows, for the ranges of samples collected, that Lake Baldwin had the highest equation response followed by Orange Lake and Lake Pearl. This coincides with the weight-volume values calculated.

Sparse hydrilla weight-volume values for the 2- to 3-m depth interval showed Lake Baldwin values (Table 7) to be higher than those for Orange Lake. Again, equations plotting hydrilla height, hydrilla-surface, and cover against biomass, show Lake Baldwin to have a higher response (intercepts and slope), and hence biomass, than those found in Orange Lake (Figures 4-6).

Plant density appears to be a major variable in determining plant biomass utilizing fathometer tracing characteristics. In Lake Baldwin, percent vertical cover, which may be sensitive to hydrilla density, was found to be the strongest of the three variables predicting sparse hydrilla (Maceina and Shireman 1980). Further investigations to determine the relationship of plant density (hydrilla weight/m^3, number of stems/m^3, and $\bar{X}$ internodal length/m^3) at various depth intervals and different bodies of water need to be incorporated into the current model for refinement.

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Table 1

White Amur Growth Rates from Lake Baldwin Calculated by Regression Analysis

	Years Following Stocking				
	0	1/2	1	1-1/2	2
$\overline{X}$ weight, kg	0.79	3.00	5.24	7.27	9.17
Growth, kg		2.21	2.24	2.03	1.90
$\overline{X}$ length, mm TL	408	592	720	807	876
Growth, mm TL		184	128	87	69

Table 2

Data and Calculations Utilized to Determine *Hydrilla* Consumption by Large White Amur in Lake Baldwin

	Date		
	9/12/79	12/22/79	3/11/80
Number of white amur	2,123	2,123	2,050
$\overline{X}$ weight white amur, kg	6.60	7.18	7.85
White amur standing crop, kg	14,000	15,250	16,100
Hydrilla standing crop, kg	781,320	362,450	32,370

	Time Interval	
	9/12/79 to 12/22/79	12/22/79 to 3/11/80
White amur standing crop, kg	14,625	15,675
Interval, days	101	80
Hydrilla standing crop decline, kg	418,870	330,080
Consumption (wet wt. hydrilla consumed/ day/fish wt./interval	28%	26%

Table 3

Total Hydrilla Volume and Percent of Lake Volume Infested with Hydrilla in Lake Baldwin

Date	Hydrilla Volume, ha-m	Percent of Total Lake Volume* Infested with Hydrilla
6-14-78	106.9	31.0
8-2-78	133.8	38.8
11-11-78	135.0	41.1**
1-6-79	125.0	36.3
3-5-79	71.5	20.8
6-21-79	69.8	20.6†

* Lake volume = 344.5 ha-m.
** Water level dropped 0.2 m below mean level; lake volume = 328.6 ha-m.
† Water level dropped 0.1 m below mean level; lake volume = 336.6 ha-m.

Table 4

Mean Weight Volume Values of Hydrilla at Each Depth Interval from Lake Baldwin

Depth Interval, m	Number of Samples	$\overline{X}$ Weight kg Hydrilla/m^3	Standard Error
1.0-1.9	4	4.51^{a}	0.53
2.0-2.9	55	1.85^{b}	0.16
3.0-3.9	48	1.62^{bc}	0.11
4.0-4.9	39	1.45^{c}	0.11
5.0-5.9	50	0.87^{d}	0.10
6.0-6.9	6	0.06^{e}	0.01

Note: Values with the same letters are not significantly different ($P < 0.05$).

Table 5

Best Fitting Regression Equations Predicting Hydrilla Biomass from Fathometer Tracing Characteristics in Three Lakes

Lake	Hydrilla Type	Water Depth Sampled m	Regression Equation*	Total D.F.	Prob. > F	r
Pearl	Thick	1.8-2.9	Biomass = 7.489 - 2.797 HYDHT -1.328 ln(HYDSUR)	43	0.036	0.387
Orange	Thick	1.7-2.5	ln(Biomass) = 2.361 - 3.431 HYDSUR	12	0.006	0.731
	Sparse	2.0-2.7	ln(Biomass) = -3.717 + 0.066 COVER +1.085 HYDSUR	18	0.006	0.688
Baldwin**	Thick	2.6-5.7	Biomass = 1.977 + 1.029 HYDHT -1.341 ln(HYDSUR)	50	>0.001	0.796
	Sparse	1.6-6.2	ln(Biomass) = -5.099 + 0.982 ln(HYDHT) +1.301 ln(COVER) - 0.281 ln(HYDSUR)	150	>0.001	0.807

* Biomass = wet weight of hydrilla, kg/m^2
HYDHT = height of hydrilla from the hydrosoil to the top of the plant, m
COVER = percent vertical cover of hydrilla on the tracing
HYDSUR = distance from the top of the hydrilla plant to the surface of the water, m

** Shireman and Maceina (1980)

Table 6

Regression Equations Predicting Hydrilla Biomass from Fathometer Tracing Characteristics in Orange Lake

Hydrilla Type	Regression Equation	Prob. > F	r
Thick	Biomass = -0.075 + 0.423 HYDHT -2.845 ln(HYDSUR)	0.066	0.648
Sparse	ln(Biomass) = -8.151 + 1.641 ln(HYDHT) +1.970 ln(COVER) +2.129 ln(HYDSUR)	0.036	0.652

Note: Independent variables utilized for equations are from those calculated from Lake Baldwin (Shireman and Maceina 1979a).

Table 7

Mean Weight Volume Values of Hydrilla (kg/m^3) In Thick and Sparse Hydrilla at Various Depth Intervals

Hydrilla Type	Depth Strata m	Lake Baldwin	Orange Lake	Lake Pearl
Thick	1.0-1.9	NC*	2.88^a(0.52)	3.03^a(0.34)
	2.0-2.4	2.98^a(0.03)	2.45^a(0.37)	1.77^b(0.16)
Sparse	1.0-1.9	4.51(0.53)	NC	
	2.0-2.9	1.80^a(0.16)	0.54^b(0.21)	

Note: Values in parentheses represent standard error of the mean. Values with the same letters are not significantly different ($P < 0.05$).
* NC = Not collected.

GENERAL STUDIES

Influence of Sediment on the Growth and Nutrition of Submersed Freshwater Macrophytes

by

John W. Barko*

Introduction

Despite the reduced structure and extent of the root system of most submersed macrophytes in comparison to terrestrial plants, roots of the former may possess many (if not all) of the functional characteristics of the latter (Tomlinson 1969; Bristow 1975). Experiments with submersed macrophytes have demonstrated the uptake of a variety of nutrients by roots and the subsequent translocation of these nutrients to shoots. In this regard, phosphorus has been examined most extensively, leading to the generally accepted consensus that submersed macrophytes can obtain their phosphorus largely from the sediment (Bole and Allen 1978; Barko and Smart 1979, 1980, 1981; Carignan and Kalff 1979, 1980). Much of the recent information available on specific processes of uptake, translocation, and excretion of phosphorus by submersed macrophytes is critically examined in Welsh and Denny (1979). Our understanding of the mobilization (i.e. uptake by roots and transport to shoots) of other nutrients by submersed macrophytes is far less complete. A relatively smaller number of studies have indicated that nitrogen (Toetz 1974; Nichols and Keeney 1976a,b; Best and Mantai 1978), iron (DeMarte and Hartmann 1974; Gentner 1977; Basiouny, Haller, and Garrard 1977), and calcium (DeMarte and Hartmann 1974) can be mobilized to a variable extent by submersed macrophytes. Additionally, carbon uptake from sediments by roots of submersed species possessing an extensive lacunar system has been demonstrated to be significant in comparison with its uptake by shoots (Sand-Jensen and Søndergaard 1979; Søndergaard and Sand-Jensen 1979).

The extent to which nutrients mobilized from sediments replace, complement, or represent an addition to nutrients obtained from the water by submersed macrophytes is unclear. Our ability to better understand the influence of submersed macrophytes on lacustrine nutrient cycles will continue to depend in large part on the resolution of this quandary. Moreover, the importance of nutrients compared to other factors affecting the growth of submersed macrophytes cannot be adequately assessed

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without better information on specific nutrient source-sink relations involving sediment, plant, and water.

Summary of Research

The capabilities of four species of submersed freshwater macrophytes in mobilizing nitrogen, phosphorus, and potassium from three different sediments were comparatively examined in relation to their requirements for these nutrients during a 10-week period of growth under controlled environmental conditions. With all species, nitrogen and phosphorus were readily mobilized from each of the sediments and concentrated in plant shoots at levels well above those required for growth. However, the mobilization of potassium from all sediments was much less effective and may have limited the growth of the species considered here. Sediments represent a large and important source of nitrogen and phosphorus for rooted aquatic macrophytes, but potassium is probably supplied to these plants primarily from the water.

Only small quantities, or none at all, of nitrogen and phosphorus were excreted from the species considered here during active growth. However, considerable quantities of these nutrients can be released to the water due to plant senescence and associated decay processes. Since a large fraction of the total nutrients, and in particular nitrogen and phosphorus, released during decay may derive from the sediment, this mechanism represents an important mode of sediment-nutrient recycling in aquatic systems.

In a subsequent related investigation, potassium uptake by *Hydrilla verticillata* Royle from sediment versus overlying water was evaluated in relation to the potassium demands incurred by this species during an 8-week period of growth. The investigation was conducted on a heterogeneous assemblage of sediments and in two solutions differing fundamentally in the presence (2.3 mg ℓ^{-1}) and absence of potassium.

Both biomass production and shoot morphology in *Hydrilla* varied significantly between solutions and among sediments. In contrast to nitrogen and phosphorus, which were readily mobilized from most sediments, potassium was mobilized from all sediments to only a minor extent by this species. Mobilization of potassium was proportional to interstitial water potassium concentration; yet on at least four of the six sediments examined, potassium supplied from sediments was insufficient to support the maximum growth of *Hydrilla*. The open water rather than the sediment appears to be the primary source of potassium supply to this species and perhaps to most other submersed freshwater macrophytes.

Where potassium was supplied in solution, sediment-related differences in the growth of *Hydrilla* negatively correlated with sediment organic matter content over the range of 1.6 to 56.2 percent dry sediment mass. It is tentatively suggested that the organic composition of sediments may influence the species composition of aquatic macrophyte communities.

A detailed account of these investigations is provided in Barko and Smart (1981), Barko (submitted), and Barko et al. (in preparation).

Ongoing and Future Research

During 1981, we plan to continue investigating the role of sediment in relation to the growth of submersed macrophytes. Recent pilot studies have indicated that the correlatively inverse relationship noted above between sediment organic content and the growth of *Hydrilla* may functionally dictate disjunctions in the distribution of this and other submersed species. We will attempt to define this relationship in more discriminate detail and to suggest causal mechanisms.

The early studies of Pearsall (1920) and Misra (1938) indicate that the growth of floating-leaved and emergent macrophytes, which are structurally more complex than deep water submersed forms, may be less sensitive to differences in sediment than the latter. Accordingly, we plan to examine the relationship between sediment composition and the growth of different submersed macrophytes with consideration given to the possible importance of sediment organic matter in affecting species succession.

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GENERAL STUDIES

Evaluation of Mathematical Models for Use in the APCRP

by

Joseph H. Wlosinski*

The Water Quality Modeling Group (WQMG) of the Environmental Laboratory has been asked to develop predictive techniques required for field office use in evaluating the environmental effects of various aquatic plant control management strategies. The approach taken in the 1980 fiscal year included conducting a workshop dealing with the objectives of the modeling approach and the evaluation of the CE-QUAL-R1 model for use within the APCRP.

Workshop

A workshop was held at WES on 19 and 20 February 1980 that addressed the use of mathematical models for predicting the environmental impact of various management and control strategies that are being developed in the APCRP. The workshop was attended by a selected group of individuals with experience in modeling and/or aquatic macrophyte biology. Workshop participants were asked to address a matrix of topics which included: (a) aquatic problem species (Table 1); (b) types of control (Table 2); (c) environmental conditions where the species occur (Table 3); and (d) a list of expected environmental problems attributable to the management action (Table 4).

Problems addressed by models

In response to the question, "Which environmental problems listed in Table 4 can be addressed by models?", the participants answered, "All problems could--with reservations." The reservations concerned the fact that although, theoretically, mathematical models can address all the questions, some of the information needed for construction of models is not available at the present time. Because of the lack of data concerning some questions, field and laboratory research studies and experiments would probably be needed before models could be developed and applied with a fair degree of success.

In combining elements of the matrix in order to make it more manageable, two groups of problems were developed. One group of problems dealt with those control measures that had immediate effects on the

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macrophytes. This situation would occur with a number of chemical controls or the use of mechanical harvesters, both of which would produce a large mass of dead plants. The problems addressed dealt with oxygen depletion, increased nutrient load, turbidity, algal blooms, and fish kills. The other group of problems dealt with delayed control techniques that would not kill large amounts of macrophytes in a short period of time. This could occur in the case of controlled release herbicides, biological control, or environmental management. Possible problems for this group are not as well defined, have more interacting variables, usually occur over longer time periods, are not as well understood, and therefore would be more difficult to model. Nevertheless, the participants agreed that models should be developed for both problem groups.

Models dealing with control measures with immediate effects were further subdivided into models for short-term (10 to 90 days) and long-term effects (months). Only a decomposition algorithm would be needed for the short-term effects unless the macrophytes were removed from the system. The long-term effects would require a model that allowed for regrowth of macrophytes. It would be similar to a model for control measures with delayed effects. A number of effects concerning community structure and function occurring after 1 year were discussed, but the reliability of models for simulating a period longer than 1 year was questioned. Part of this concern was due to the validity of present water quality or ecological models. Many of these models are untested or are tested only in a qualitative fashion. Quantitative tests are often incomplete, are not standardized, or show problems with the models.

Because some of the control measures do not kill all of the plants in an area in a short period of time, it will also be necessary to have the capability to predict plant growth. This capability, besides predicting environmental problems, could eventually be used to predict suitability of a particular area for macrophyte colonization. There was general agreement that a model to predict macrophyte growth should have spatial resolution in the vertical direction. Justification for this recommendation was that most aquatic systems have strong abiotic gradients such as light, redox, temperature, and pressure along the vertical axis, with a concomitant change in rates for biotic processes. Titus et al. (1975) have developed a model (WEED) with such resolution, and it was recommended that this model act as a starting point for an APCRP macrophyte growth model. WEED is a mechanistic model that incorporates the main physiological processes of photosynthesis, respiration, and excretion, with biomass divided into leaves, stems, roots, and carbohydrates. The main forcing functions are light and temperature.

Types of models needed

Everyone agreed that more than one model would be needed to address the entire problem matrix. The models mentioned ranged from simple regression models to two-dimensional horizontally or vertically averaged coupled hydrodynamic-biological/chemical models. Their use would be based on study objectives and available information. Participants also agreed that if a simple model could answer the question, then there was

no need to develop a complex model for the same problem. This same idea has been voiced by a number of authors (Alonzo 1968; Caswell et al. 1972; Crissey and Phillips 1974; Innis 1975; and O'Neill 1970).

Most participants supported the concept of developing mechanistic models of ecological processes in aquatic ecosystems, although a good deal of skepticism was voiced concerning the application of such models as accurate predictors during the early stages of their development. Some of the support for mechanistic models was due to their heuristic role, so that a better understanding could be gained concerning those processes that regulate macrophytes as well as other components of aquatic ecosystems. Part of the skepticism dealt with the ambitious goal of addressing the entire problem matrix with the use of mechanistic models that should require few measurements and parameters, be realistic in the representation of processes, be applicable to a wide range of systems, but be relatively precise in its predictions for a specific situation. This may be difficult, if not impossible, for, according to Levins (1966), there is a trade-off between realism, generality, and precision for a particular model. Problems dealing with the lack of information, a good data base, and accurate conceptual models led the group to recommend that mechanistic models are needed, but that their development be a continuing effort, keeping pace with the science. This disciplined approach would require that deterministic model development be coupled with a strong experimental program aimed at studying the critical ecological relationships involved. Such a program would keep pace with and stimulate the increasing body of knowledge concerning macrophytes and their environment.

Evaluation of CE-QUAL-R1

CE-QUAL-R1 is a one-dimensional (horizontally averaged) mathematical model that represents the vertical distribution, in a lake or reservoir, of the following variables: thermal energy, shortwave radiation, dissolved oxygen, two algal assemblages, zooplankton, benthos, coliform bacteria, ammonium-N, nitrate-N, nitrite-N, phosphate-P, detritus, sediment, alkalinity, total dissolved solids, dissolved oxygen residual, daily oxygen demand, pH, and carbon dioxide-C. Three fish compartments are also included in the model, although their vertical distribution is not predicted. Model input includes initial estimates for all model components, coefficients for the equations of the model, and information concerning driving variables. Output consists of vertical profiles and downstream release values of the water quality variables and can be represented in tabular or graphical form. This model, or its predecessor, has been applied to a number of Corps of Engineers project studies (e.g., Thornton, Ford, and Robey 1976; Thornton et al. 1977; Hall et al. 1977; Ford et al. 1978 and 1979; and Ford, Thornton, and Robey 1977).

Application of the model for other studies performed by the WQMG has shown that temperature is an important factor for most of the

variables included in the model. For ease in calibrating the model, subroutines dealing with temperature and the water budget were separated from water quality subroutines, thus creating a thermal model. This study followed the example of the other studies within the WQMG--that of calibrating the thermal portion of the model before attempting the calibration of the entire CE-QUAL-R1 model.

Data used for the evaluation of the model were collected for the Lake Conway Large-Scale Operations Management Test (LSOMT). The Lake Conway system is comprised of a set of five interconnected pools located just south of Orlando, Florida. The pools are Lake Gatlin, the West and East pools of Little Lake Conway, and Middle and South pools of Lake Conway. Although data were collected at all five pools, only the Middle pool was modeled. The Middle pool has an area of 2.99 km^2 and a volume of 17.9×10^6 m^3. The average depth of the pool is 6.0 m, with a maximum depth of 12 m. The theoretical hydraulic residence time is approximately 3 years. Further information concerning the Lake Conway study site can be found in reports by Theriot (1977), Nall and Schardt (1978), Guillory (1979), Conley et al. (1979), and Blancher and Fellows (1979).

Simulations

The thermal portion of CE-QUAL-R1 was calibrated with those coefficients dealing with the water budget and the hydrothermal regime. Coefficients concerning depth versus area and depth versus volume were obtained using data supplied by E. Blancher.* Coefficients for the hydrothermal regime were calibrated using data, measured monthly, from Comp (1979).

Blancher's estimate of lake surface area (2.99 km^2) and lake volume (17.9×10^6 m^3) corresponds to model estimates of 3.23 km^2 and 17.7×10^6 m^3, respectively. The water surface elevation was always within 0.3 m of measured values. Comp's (1979) data show that slight stratification began between the 10 February and 10 March sampling period. Although the model predicted periods of slight stratification and breakup in January and early February, the onset of a permanent stratification occurred in mid-February. Measured data show that the fall overturn, to a depth of 9 m, occurred between the 12 September and 6 October sampling dates. Fall overturn predicted by the model occurred during this same time.

Data used for verification were collected by the Orange County Pollution Control Department. Unfortunately, the data were reported as being collected for 2 or 3 days, making comparison with model predictions difficult. In addition, measurements were rarely taken below 5 m. Initialization values for the verification simulation were taken from the 26 and 27 January 1976 sampling period. Simulation was for a period

* Personal Communication, Mar 1980, Marine Environmental Science Consortium, Mobile, Alabama.

of approximately 34 months, ending in October of 1978. An example of temperature predictions from the verification simulation is presented in Figure 1. In general, model predictions were similar to the measured data. The principal difference was that the model prediction in the winter was slightly lower, and in the summer slightly higher, than measured data. The model predicted thermal stratification for the spring and summer of all 3 years. Unfortunately, not enough measured data were available to validate this prediction. The predictions for the water budget were also satisfactory. For the entire 34-month period, the predicted depth of water was within 0.5 m of values reported by the U. S. Geological Survey, Orlando, Florida.

Although the water quality portion of the CE-QUAL-R1 model was calibrated using the Lake Conway data, the data set was not considered suitable for a proper evaluation of the model because the objective of the Lake Conway Study was not to evaluate CE-QUAL-R1. The Lake Conway LSOMT was planned and the data were collected, analyzed, and reported before the decision was made to evaluate the model by simulating Lake Conway. The main problems with the data for evaluation purposes were that collection times by different contractors were not coordinated, few samples were taken in the hypolimnion, little information was available on system function, and actual nutrient concentrations were usually reported at detection limits. Results from the water quality simulations, keeping these problems in mind, appeared to be reasonable. Examples of the output, along with measured values, are given for the surface layer for algae in Figure 2 and for oxygen in Figure 3. Other examples of predicted versus measured values can be found in Wlosinski (1981b).

Model assumptions

All models are, by definition, simplified representations of the prototype. One of the benefits of this simplified representation is that the model can be manipulated for less cost and in a shorter time than experimentation on the prototype. One of the costs associated with this benefit is that a number of assumptions are used in order to simplify the real system, and these assumptions, then, impose limitations on the use and interpretation of model results. The major assumptions and limitations of the present version of CE-QUAL-R1 are presented below.

One-dimensional assumption. A lake can be represented by a vertical series of completely mixed horizontal layers. Thus, only the vertical dimension is retained during computation, and concentration gradients occur only in one direction. Therefore, all concentrations of water quality constituents in any given layer are parallel to the water surface both laterally and longitudinally. Because of this constraint, the model cannot, in one simulation, predict differences in concentrations occurring in different parts of the lake. In addition, all inflow and outflow quantities and concentrations are instantaneously dispersed and homogeneously mixed throughout each horizontal layer. This assumption should not affect the simulation of Middle pool of Lake Conway as much as it might affect the simulation of most reservoirs, but it must be kept in mind when simulating larger lakes with coves and embayments, especially if nutrient point sources are present.

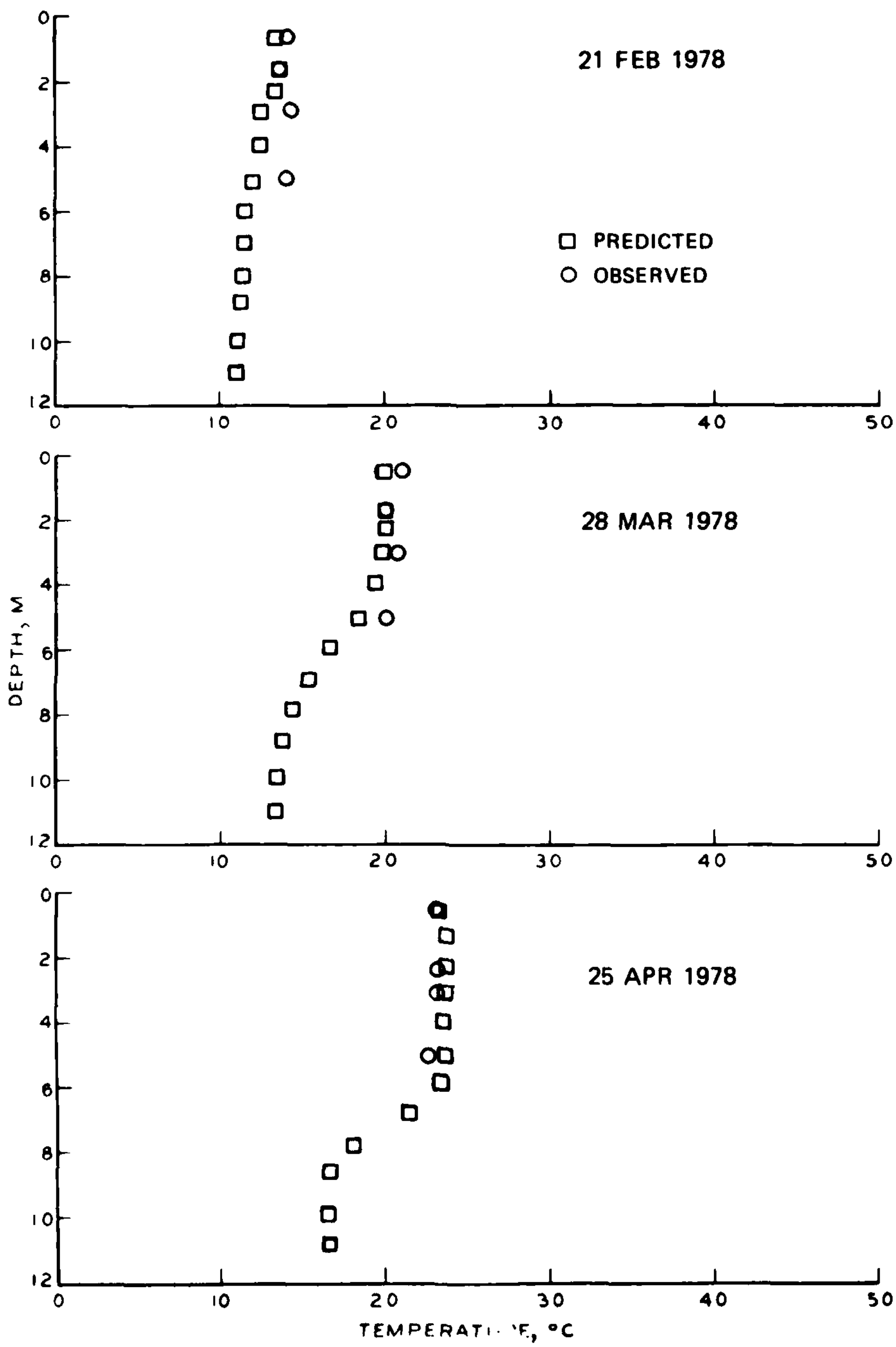

Figure 1. An example of temperature predictions from the verification simulation of the thermal portion of CE-QUAL-R1

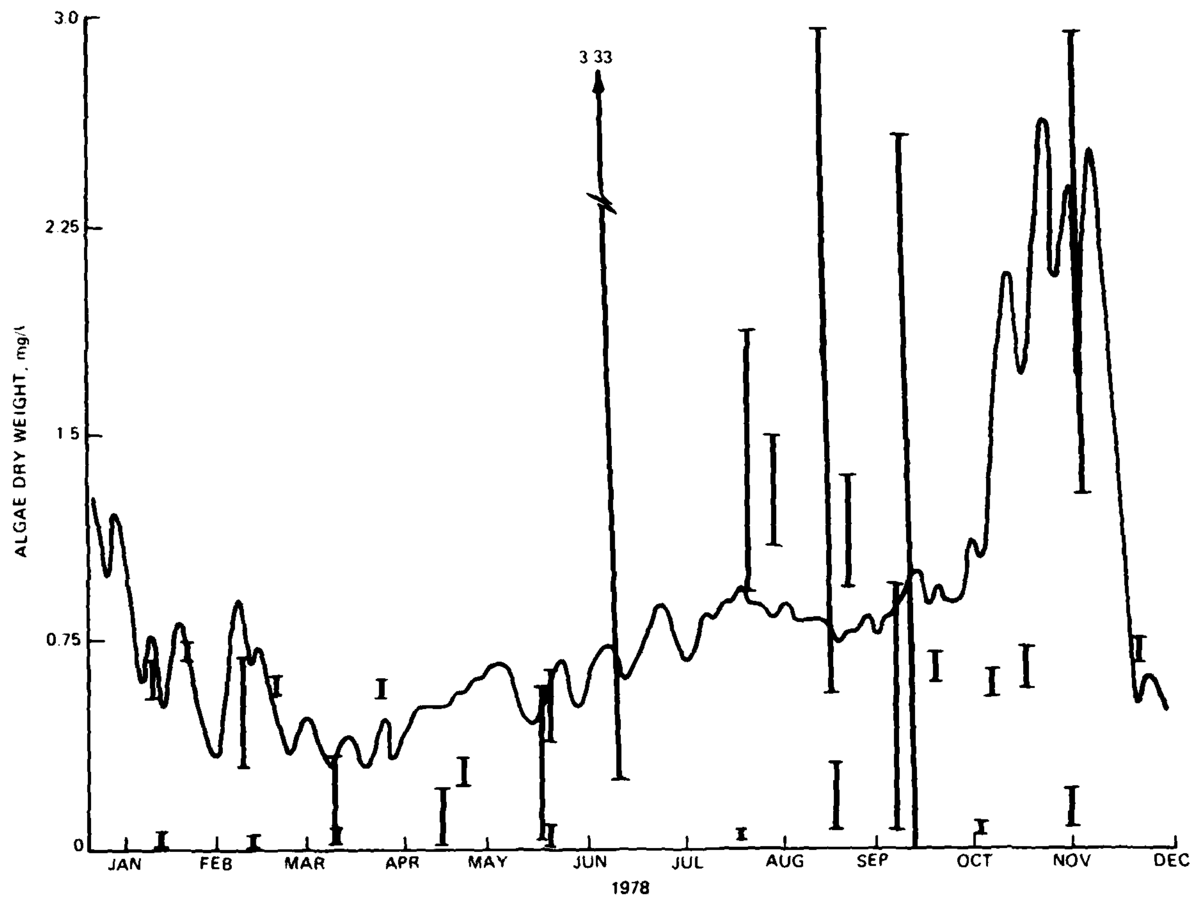

Figure 2. Simulation of algae dry weight in the surface layer. Vertical bars represent maximum and minimum measured values

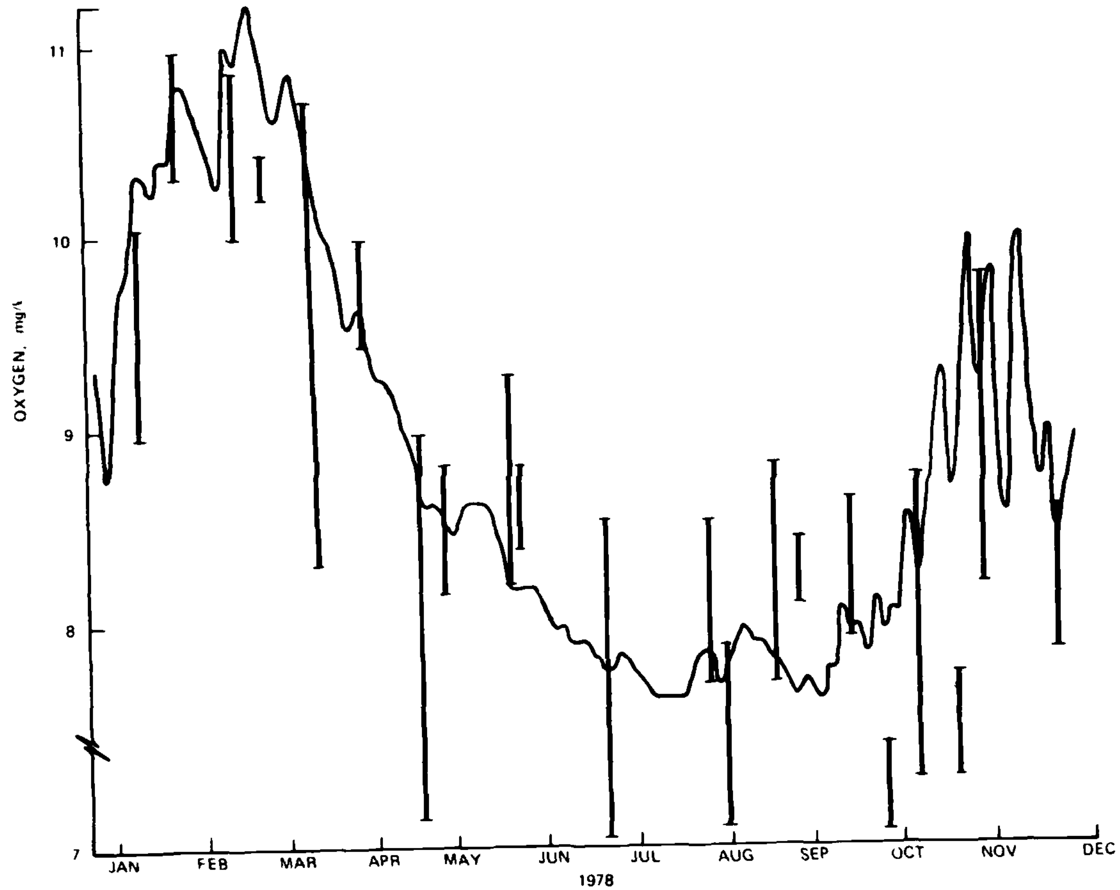

Figure 3. Simulation of oxygen in the surface layer. Vertical bars represent maximum and minimum measured values

Density function. The density of water is assumed to be only a function of temperature. Contributions to water density by suspended and dissolved solids are not currently included in the model. Any model application in which the suspended and dissolved solids contribute substantially to the density of water could be questioned. This assumption is not very significant for the present study since measured values for suspended and dissolved solids are low.

Simplified ecology. Many of the biological [illegible]s that exist in a lake can be lumped together for modeling purpo[illegible]. In all cases the aggregation is quite severe--one compartment each for all zooplankton and benthic species, two compartments for all algal species, and three compartments for selected fish species. Because of this aggregation, individual species dynamics and interactions within the ecosystem cannot be considered. This is a difficult assumption to assess and can only be determined by repeated model verification.

Conservation of mass. The dynamics of each biological and chemical component can be described by conservation of mass. The mass of elements, such as carbon, oxygen, nitrogen, and phosphorus, is accounted for by considering the inflows, outflows, and internal changes in the form of the elements, which are neither created nor destroyed. Some problems dealing with the conservation of mass were found, and have since been corrected.

Kinetic principle. The kinetic principle implies that internal changes that occur in the lake do so through processes such as ingestion, respiration, and photosynthesis. This assumption should not adversely affect the interpretation of model predictions.

Aerobic environment. Chemical and biological processes occur in an aerobic environment. While CE-QUAL-R1 does incorporate simple default rate coefficients when dissolved oxygen approaches zero, the model predictions are not realistic under anaerobic conditions. This assumption results in the inability to simulate the buildup of a dissolved oxygen deficit under anaerobic conditions. Also, the changes in the solubility and formation of various chemical species and interactions between the sediment and water under anaerobic conditions cannot be simulated. This assumption probably had some effect on predictions since anaerobic conditions were present in the hypolimnion, but because the Middle pool is relatively shallow, these effects should be minimal. An anaerobic subroutine is currently being developed as part of the WES Environmental and Water Quality Operational Studies (EWQOS) Program.

Ice-free environment. The model does not contain an ice cover algorithm. Model predictions are therefore limited to ice-free periods. This assumption had no effect on the Lake Conway simulation, and the assumption should be eliminated in the future with the addition of an ice cover algorithm, which is being prepared as part of the EWQOS Program.

All inclusive variable. All of the components in a reservoir are represented in the model, unless they do not interact significantly with modeled variables. As noted above, these components may be lumped

together, but it is assumed that they are included. Since macrophytes and their associated epiphytes were not included in the model, and since they affect other variables, the addition of macrophytes and epiphytes would change the present predictions. Fontaine (1978) estimated that planktonic gross production was only 38 percent of community gross production. By implication, the macrophyte and epiphyte community supports 62 percent of gross production and may severely affect oxygen and nutrient concentrations. Part of this problem may be mollified by the fact that the model was calibrated using measured data, and algal coefficients, for example, may have been set in such a manner as to include some effects attributable to macrophytes.

It is recommended that a macrophyte algorithm be included in the model before use by the APCRP. Since one of the recommendations from the workshop concerning the modeling of aquatic macrophytes was that a macrophyte algorithm be spatially variable in the vertical direction (Wlosinski 1981a), this should pose no serious problem.

Inflow placement. The vertical placement of inflowing water within the lake is determined by temperature only. The density of an inflow is determined from its temperature, and it is placed into the horizontal zone of comparable density. Contributions to the density of the inflow by suspended and dissolved solids are not currently included in the model. In addition, all water entering the lake is from inflowing water. In the present study, the greatest portion of water entering the lake was from rain falling directly on the lake. Unless values for temperature of inflowing water are set at or above surface temperature, rainfall, with its associated nutrients, can be added to the wrong layer. Since the ratio of rainfall to lake volume is usually small, this problem should not be very significant, but should be corrected for realism.

Diffusion mechanism. Internal dispersion of thermal energy and mass is accomplished by an effective diffusion mechanism that combines the effects of molecular diffusion, turbulent stirring and mixing, and thermal convection. The transport is therefore assumed to be proportional to an effective diffusion coefficient and a concentration gradient. If is important to note that although the diffusion gradient among layers is based on the concentration differences of the individual constituents such as dissolved oxygen or nitrate, the effective diffusion coefficient is always based on temperature. In many instances, mass diffusion coefficients may not be equivalent to thermal diffusion coefficients. The impact of this assumption should not be as great after the incorporation of an integral energy algorithm planned as part of the EWQOS Program.

Model development

The CE-QUAL-R1 model is currently being improved as part of the EWQOS Program. Current developments and future changes will affect the compartments dealing with phytoplankton, zooplankton, benthos, sediment, pH, carbon dioxide, suspended solids, temperature, and fish. Plans have been made to add algorithms dealing with ice cover, anaerobic processes, and macrophytes. In addition, the model may be run in a stochastic

fashion, graphical output is being improved, and a user's manual (USAE Waterways Experiment Station, in preparation) is being prepared. All of these changes should enhance the use of CE-QUAL-R1 in the APCRP.

Because of these enhancements and because of the satisfactory results from the simulations, it was concluded that the CE-QUAL-R1 model would be useful to the APCRP in predicting certain water quality variables.

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Table 1

Problem Species of Aquatic Macrophytes

Scientific Name	Common Name
Myriophyllum spicatum	Eurasian watermilfoil
Hydrilla verticillata	Hydrilla
Eichhornia crassipes	Floating waterhyacinth
Egeria densa	Brazilian elodea
Alternanthera philoxeroides	Alligatorweed
Potamogeton illinoiensis	Illinois pondweed
Elodea canadensis	Common elodea
Najas quadalupensis	Southern naiad
Pistia stratiotes	Waterlettuce
Cabomba caroliniana	Fanwort

Table 2

Types of Control for Aquatic Macrophytes

Chemical

2,4-D
  DMA (Weedar 64)
  BEE (Aqua-Kleen)
Endothalls
  Aquathol K
  Aquathol
  Hydrothol 191
  Hydout
Diquat
Glyphosate (not yet cleared for aquatics)
Amitrol T
Dichlobenil
Fenac
Simazine

Biological

Insects
  Neochetina eichhorneae
  Neochetina bruchi
  Arzama densa
  Sameodes albiguttalis
  Agasicles hydrophila
  Vogtia malloi
  Litodactylus leucogaster
  Acentropus niveus
Fish
  Ctenopharyngodon idella
Pathogens (Fungi)
  Cercospora rodmanii
  Fusarium roseum

Mechanical

Harvesters
  Aqua-Trio (Aquamarine)
  Allied Aquatics
  Limnos Ltd.
  Altosar

Environmental Management

Water level fluctuation (drawdowns)
Plant competition

Table 3

Environmental Conditions of Aquatic Macrophytes

Area
Rivers
Reservoirs
Streams
Canals
Lakes
Ponds
Backwater areas (tree stumps, etc.)
Characteristics
Waterflow - 0 to slow moving
Depths where most problems exist - >0 to 12 m
Water temp - tropical (South Florida) to cold (Washington State)
Water body size - <0.1 ha to thousands of hectares
Nutrient load
Various
Sediment load
Various
Turbidity
0 to cloudy
Potable waters
Irrigation waters

Table 4

Possible Environmental Problems Due to Control Measures

Increased nutrient load
Increased turbidity
Elimination of desirable species and/or habitat (fishes and plants)
Algal blooms
Fish kills
Contamination of water near potable supply intakes
Oxygen depletion
Buildup of toxic substances
Shoreline erosion due to elimination of shoreline vegetation
Degradation of aesthetic qualities

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by

Dana R. Sanders, Sr.*

Introduction

Objective

Biological control involves the use of one or more species to control the population level of any species that is adversely impacting a natural ecosystem or man's use of that ecosystem. Several aquatic plant species, all of which have been introduced into the United States, constitute a serious threat to native aquatic ecosystems in this country, and also significantly threaten man's use of these systems. The overall objective of the biological control technology development element of the Aquatic Plant Control Research Program (APCRP) is to provide the operational capability to use biological agents for the control of problem aquatic plant species in the shortest time possible.

Approach

This element of the APCRP consists of the following five major research tasks:

Task I - Search for candidate biocontrol agents.

Task II - Quarantine research to establish host specificity and control potential.

Task III - Petition for permission to release from quarantine.

Task IV - Field release and establishment.

Task V - Development of management strategies.

As you will see in the presentations that follow, research is currently in progress that addresses each of these research tasks.

Current Status

Efforts to control aquatic plants through the use of biological agents have focused on four aquatic plant species:

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.)

Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms)

Hydrilla (*Hydrilla verticillata* (L.F.) Royle)

Eurasian watermilfoil (*Myiophyllum spicatum* L.)

Alligatorweed

Three insects resulting from APCRP-sponsored research were released on alligatorweed during the early 1960's. By 1970, there was a significant reduction in the alligatorweed population in the southeastern United States. The level of control achieved in most areas was attributed primarily to activity of the alligatorweed flea beetle (*Agasicles hygrophila* Selmon and Vogt), with lesser effects produced by the alligatorweed stemborer moth (*Vogtia malloi* Pastrana). Effects of the alligatorweed thrips (*Amynothrips andersoni* O'Neill) on the decline on alligatorweed were not known. By 1978, there was a resurgence in the alligatorweed population in many areas, presumably due to the combined effects of abnormally low winter temperatures and flooding on the insect populations. However, *Agasicles* and *Vogtia* persisted in most areas, and controlling population levels of these two species had redeveloped by 1980, thereby producing a decline in alligatorweed populations in many areas. *Agasicles* failed to become established or persist in areas of normally low winter temperatures (e.g., North Carolina, South Carolina, northern Alabama), and also had not provided adequate control of alligatorweed in areas of significant water level fluctuations (e.g. southeastern Texas). This was especially true in areas where the alligatorweed was exposed to dry conditions for a portion of the growing season. *Vogtia*, which is more tolerant of the above environmental conditions, exerted a controlling effect in some areas in which *Agasicles* could not persist. Additional research is needed to develop management strategies for effectively controlling alligatorweed through the use of biological agents in areas where the above described environmental conditions occur.

Waterhyacinth

Three insect species have been released in the southeastern United States for the control of waterhyacinth. Two species of waterhyacinth weevils, *Neochetina eichhorniae* Warner and *Neochetina bruchi* Hustache, were released in 1972 and 1974, respectively. The Argentine waterhyacinth moth, *Sameodes albiguttalis* Warren, was released in Florida in 1977 and in Lousiana in 1979. Three years after the release of the *Neochetina* species, it appeared that the insects were exerting little, if any, controlling effect on the populations of waterhyacinth. However, evidence obtained by 1980 suggests that the weevils may now be significantly impacting waterhyacinth in many areas. Massive population levels of these species, exceeding population levels known to kill waterhyacinth under greenhouse conditions, now occur in many areas of Louisiana and Florida. *Sameodes* populations are currently in the developmental stage in Florida and Louisiana, and this research effort will be discussed by Dr. Center and Mr. Russell Theriot in later presentations.

In addition, two native species--a moth, *Arzama densa* Walker, and a leaf-spot fungus, *Cercospora rodmanii* Conway,--have been found to significantly impact waterhyacinth. Neither of these species is being used at a truly operational scale at this time, but both are being intensively pursued as potential operational tools. To effectively utilize *Arzama*, it will be necessary to achieve the capability of producing massive numbers of individuals for field releases. Dr. Baer will discuss this effort in a later paper. Research on *Cercospora rodmanii* has progressed to the level that a dry powder formulation has been developed and was experimentally applied by fixed-wing aircraft to a study site in Louisiana in 1980. Mr. Edwin Theriot will discuss this research later in the proceedings.

A comparable level of biocontrol of waterhyacinth has not yet been achieved as has been demonstrated for the biocontrol of alligatorweed. However, the prospects are encouraging, and the next 2 or 3 years should provide a good indication of the level of waterhyacinth control that can be achieved by biocontrol agents.

Hydrilla

With the exception of the white amur (*Ctenopharyngodon idella* Val.), no biological agents have been released on *Hydrilla* in the United States and the prospects for the near future are not promising. Presently, only one fungal agent, *Fusarium roseum* 'Culmorum' (L. K. ex Fr.) Synd. and Hans., has been found to significantly affect hydrilla. Dr. Charudattan will discuss this research. Only one species of insect, the moth *Paraponyx* (=*Nymphula*) *rugosalis*, is being investigated as a potential biocontrol of hydrilla. This insect has just been introduced from the Panama Canal Zone into quarantine at the Gainesville Biocontrol Laboratory, and Dr. Buckingham will discuss this research effort. A domestic survey for insects on hydrilla is in its final stages, and Dr. Balciunas will report on this effort. Overseas searches for candidate hydrilla biocontrol insect species are now under way in Africa and Australia, and similar searches are already scheduled in southeast Asia and Australia. Promising species resulting from these surveys will be introduced into quarantine in this country for host specificity and efficacy testing.

Eurasian watermilfoil

Only one insect species, the weevil *Litodactylus leucogaster* (Marsham), has been released on Eurasian watermilfoil in the United States. Its impact on Eurasian watermilfoil will be limited to a reduction in the number of viable seeds produced, and therefore *Litodactylus* will not likely produce a significant impact on existing field populations. A domestic survey for insects that feed on Eurasian watermilfoil has been conducted, and Dr. Balciunas will discuss this research. Overseas searches for insects and plant pathogens of Eurasian watermilfoil have been conducted, but no promising biocontrol agents have been found. Massive declines of Eurasian watermilfoil have occurred in several areas of the United States, but definitive causal agents have not been found. One possible explanation for these declines is that one or more species of microorganisms normally associated with the rhizosphere of Eurasian

watermilfoil are induced by abnormal environmental conditions to produce lytic enzyme capabilities. In such cases, these normally nonpathogenic microorganisms temporarily act as pathogens, thereby producing a decline in the population of Eurasian watermilfoil. To determine whether or not such phenomena occur and to determine if a similar condition can be artificially produced, Dr. Gunner of the University of Massachusetts (Amherst) is conducting a study to isolate and identify microorganisms normally associated with the rhizosphere of Eurasian watermilfoil, to expose candidate microbial species to environmental conditions that favor production of lytic enzyme strains, and to determine the effects of any artificially produced lytic enzyme strains of the microbial agents on the growth of the host plant. He will discuss the progress of this research effort.

In-House Research

Most of the in-house research efforts consist of the transfer of biocontrol technology to operational elements, while obtaining data useful in developing more effective strategies for the management of the target plant through the use of biocontrol agents. Projects currently under way include the Large-Scale Operations Management Test of insects and pathogens for the control of waterhyacinth in Louisiana, the Panama Canal Aquatic Plant Control Assistance Project, and a recently initiated Galveston District Project. The first two of these will be discussed in detail later in the meeting. The Galveston District Project has just been initiated, and the first report on this work will be presented at the next meeting.

Effects of temperature on *Sameodes albiguttalis*

The objective of this research is to determine the effects of temperature on the survival and over-wintering ability of *Sameodes albiguttalis*. The study, which is approximately one half completed, involves the exposure of first, third, and fifth instar *Sameodes* larvae to temperatures ranging from 0° to 100°C under controlled environmental conditions. Results thus far indicate that first instar larvae can survive exposure to 1 hr of 0°C temperatures, but complete mortality results when the exposure time is increased to 4 hr. Higher temperatures produced no mortality of the first instar larvae. In addition to completing the tests on third and fifth instar larvae, tests will be performed to determine the temperatures that occur inside waterhyacinth petioles when exposed to various ambient air temperatures.

Compatibility of *Cercospora rodmanii* with spray additives

A study was conducted to determine the effects of commercially available spray additives on the viability of *Cercospora rodmanii*. Preliminary results indicate that 10 of the 11 surfactants tested caused a significant decrease in viability of the propagules in the *Cercospora*

rodmanii formulation. Only Nalcotrol produced no significant decrease in viability of the formulation as compared to controls. The range of decreased viability was 25 to 81 percent, with an average decrease in viability of 51 percent. The impact of these surfactants on the actual field infectivity of *Cercospora rodmanii* has not been determined, but the reduction in viability should be partially offset by the increased percentage of the total formulation held on the waterhyacinth leaves when surfactants are used in the spray mixture.

New Starts

Only one new start is scheduled for FY 81. This project will consist of an investigation to determine the feasibility of using lytic enzyme-induced strains of normally nonpathogenic microorganisms associated with the rhizosphere by hydrilla to control this troublesome aquatic plant species. This study, patterned after the study being conducted by Dr. Gunner on Eurasian watermilfoil, will focus in FY 81 on the isolation and identification of microbial species associated with the rhizosphere of hydrilla.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

The Dispersal of *Sameodes albiguttalis* (Lepidoptera:Pyralidae) and its Efficacy as a Biological Control of Waterhyacinth

by

Ted D. Center*

Objectives

The initial objectives of this project were the release and establishment of *S. albiguttalis* for the biological control of waterhyacinth (*Eichhornia crassipes*). These goals have been achieved and emphasis has been shifted towards evaluating the dispersal and efficacy of this insect. Estimates of dispersal rates are important due to the possibility that insect populations may not persist during the winter in the more northerly areas of the range of waterhyacinth. If this occurs and the southern populations do not disperse northward with sufficient rapidity, then it will be necessary to re-release and re-establish populations in those areas on an annual basis. This would be a cost-intensive effort and one that, it is hoped, can be avoided.

The objectives for evaluating the efficacy of this insect are twofold. First, it is hoped that it will be possible to estimate the value (i.e. cost:benefit) of the control obtained by this and other biological agents. Second, it is desired to determine the best management approach for control of waterhyacinth so as to avoid the interference of traditional control approaches with biological control, yet still achieve comparable results.

Approach

Sameodes albiguttalis was reared in a greenhouse and released at 20 locations, mostly in southern Florida. The locations were examined repeatedly to ascertain whether self-perpetuating populations had been established. Once this was determined, nearby locations were repeatedly examined to ascertain if short-range dispersal had begun. In south Florida, this phase was considered complete once populations had been found north of U. S. 84 in Broward County.

Following the success of the establishment and short-range dispersal phases, a survey was begun to estimate the rate of long-range

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dispersal of these populations throughout the state. Since populations were only originally present in a few restricted localities and not elsewhere, the minimum rate of dispersal could be estimated according to the maximum time required for the population to move from one area into another. The phrase "minimum dispersal rate" is used here because an estimate based upon the interval between the time that the insects were released at one location and the time they were found at the next represents the slowest rate that they could have moved across the intervening space.

The survey was designed to determine the presence or absence of populations at various sites. A grid system was used as the basis of the survey and was derived from the U. S. Geological Survey (USGS) 7.5-min quadrangle map (see Figure 1). Each quadrat on the grid was coded with coordinates corresponding to the respective rows and columns which delineate the USGS quadrangles. The survey focused primarily upon locating *S. albiguttalis* within the rows, thus indicating movement in a north-south direction, and secondarily within the columns.

The survey was conducted in the following manner. Waterhyacinth populations at or near the original release sites were intensively examined until any instar of *S. albiguttalis* that could be positively identified was found. These were collected and preserved to provide a permanent record for the specific locality. The search area was then expanded to include more peripheral areas. This was repeated until no *S. albiguttalis* were found and it was fairly certain that the approximate limits of the distribution of the insect were established. All localities were then precisely plotted on a large 1:250,000-scale map and coded to indicate whether *S. albiguttalis* was found at each specific site. This information was then transferred to the grid map. Each quadrat on the grid was coded to indicate whether or not waterhyacinth was found within that area and, if it was, whether *Sameodes* was present. If either waterhyacinth or *S. albiguttalis* were ever found within a quadrat, they were considered to be present there whether they could later be found or not.

As the range of *S. albiguttalis* began to expand, surveys were continued to re-establish the limits of distribution. Sites were first examined well ahead of the advancing population front and from there back towards the known populations until the presence of the insects was established. Then, the areas progressively farther away from the known populations were re-examined more intensively until no insects could be found. Although it was not possible to test the accuracy of this system, it appeared to be very efficient and relatively precise (i.e. repeatable) and represented the best estimate of the distributional limits.

Since the southern populations could only move north (or rather, since any southward movement was irrelevant) new zones of interception were always selected to the north. If a record had previously been established for any quadrat within a row on the grid, preference was given to surveying within rows further north. This survey procedure was continued until it was determined that the range of the insect had expanded to the Georgia-Florida border.

In June 1979, a second survey was begun to provide quantitative estimates of the *S. albiguttalis* populations along a north-south transect extending nearly the entire length of the state. A total of 10 areas were selected at intervals of approximately 1/2°N latitude along the primary transect. A secondary transect was then established at a site located within each sampling area and 20 waterhyacinth plants were examined at each of ten points on this transect (a total of 200 plants examined at the site). Each plant was evaluated for the presence or absence of damage by *S. albiguttalis* larvae and only plants which appeared to be suitable to *S. albiguttalis* were examined. Data were and are still being collected along the primary transect at 4-week intervals on a quarterly basis. This system enables temporal comparisons of the abundance of *S. albiguttalis* as a function of latitude.

Studies of the efficacy of *S. albiguttalis* are only now beginning. At present, the main effort is directed towards developing an appropriate methodology. Thus far, the best approach seems to be one of population studies of specific plant organs and evaluations based on the mortality, longevity, and production of these organs by the plant as affected by various biological control organisms. It is hoped that these data will permit the development of fiduciary tables for such structures as the leaves and the stem apices of the whole plant.

Current Status

Sameodes albiguttalis has been released, is well established in Florida, and has now dispersed throughout the peninsular portion of the state. The original survey is now complete although the transect survey will be continued through the spring of 1981 in order to determine whether the winter temperatures in the northern part of the state caused the extirpation of local populations in that area. Efficacy studies are now beginning and will be fully implemented by early 1981.

Significant Accomplishments

During the period between January 1979 and June 1980, a total of 330 sites were examined throughout Florida. The presence of *S. albiguttalis* was confirmed at 170 (or approximately 52 percent) of these. If time had been available to re-examine all of the sites, *S. albiguttalis* would have been found at most of them. Hence, it is probably safe to say that this insect is now established on nearly every suitable waterhyacinth population in Florida.

Figure 1 illustrates the nearly completed survey and shows all of the quadrangles which were checked and the results for each. The open circles indicate that, at the time the area was surveyed, waterhyacinth was found but *Sameodes* was not. At the present time, *Sameodes* probably occurs in all of these areas but most have not been re-examined.

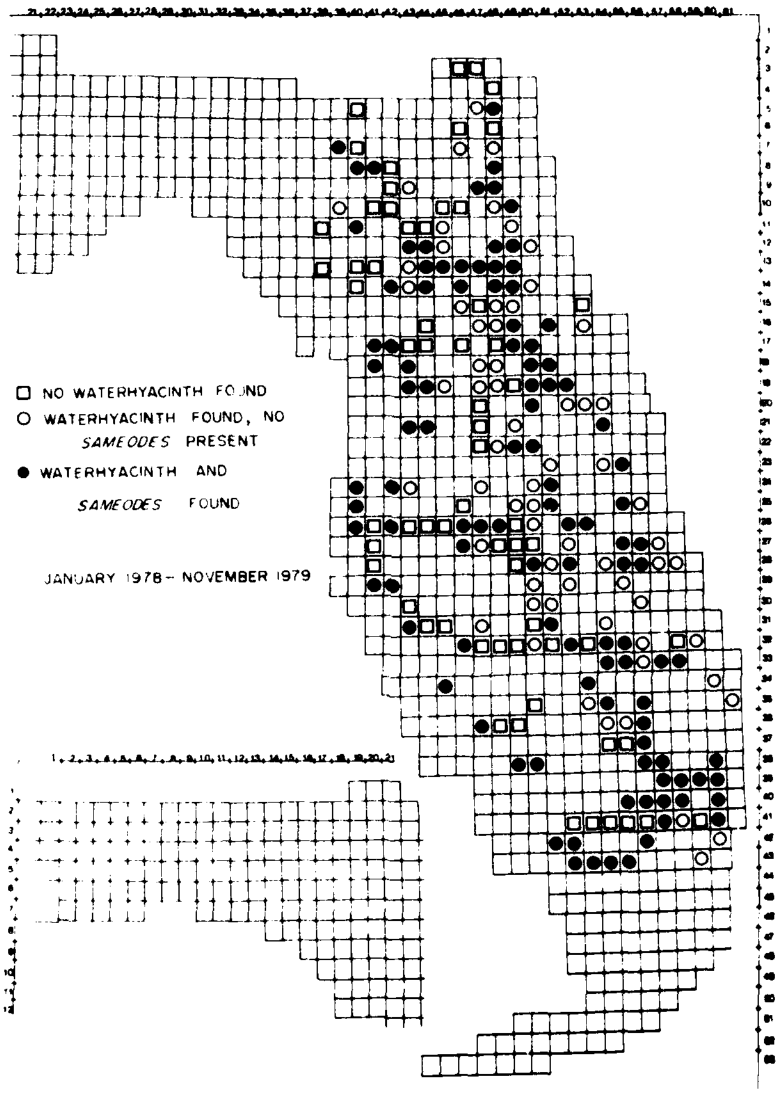

Figure 1. The results of the *Sameodes albiguttalis* dispersal survey showing the grid system employed and the findings in each quadrangle surveyed. Once a record of *S. albiguttalis* was confirmed within a row on the grid, the examination of sites farther north was given priority over filling in gaps in the distribution of known populations. Hence, many of the sites at which waterhyacinth was found but *S. albiguttalis* was not were never re-examined. Probably most now have established populations of the insect

It has now been determined that *Sameodes* is established up to the Florida-Georgia border and throughout the peninsular portion of the state. Figure 2 illustrates the approximate limits of the range of *Sameodes* at different times during the dispersal study. The southern-most population first began to disperse locally in January 1978 and in February they were first found north of U. S. Route 84 in the Miami Canal. By June, the range increased to include nearly all of Lake Okeechobee.

The western-most population (St. Petersburg) appeared to expand very slowly, apparently because the population was very isolated and relatively sparse. The presence of a population at the release site was first apparent in June 1978 and populations were not found east of Tampa Bay until May 1979. The populations expanded farther in June 1979 but still appeared to be restricted to a relatively small area.

By July 1979, there were relatively continuous populations established from Lake Okeechobee through the central portion of the state primarily in the Kissimmee River system and at the headwaters of the St. John's River. The source of these populations appeared to be the southern sites because the western sites still seemed relatively disjunct. By August, however, the populations were continuous from an Orlando-Tampa line south and the southern and western populations could no longer be distinguished.

By November 1978, the range of the insect had increased to just south of Jacksonville. This was somewhat artificial, however, by virtue of an isolated population located near Green Cove Springs. Otherwise, the populations did not extend north of Lake George. During the winter of 1979-80, the Green Cove Springs population seemed to have been extirpated and the northern-most limit of distribution was again approximately at Lake George.

The northern-most release in Alachua County did not result in widespread populations. Although a population was obviously present, it seemed to be a marginal one. No evidence of dispersal to nearby sites was ever obtained. In May 1980, however, *Sameodes* was found near the release site and at every site examined between there and Lake George. It is felt that this represented new population growth and movement from the extensive southern populations rather than from the Alachua County site. This massive movement continued and by June populations were discovered from near Lake City and north of Jacksonville.

If it is assumed that the populations from the south moved northward to result in the populations found in Green Cove Springs in November, then the net northward population movement was ca. 430 km from February to November. Over the 10-month period, then, the rate of dispersal was ca. 43 km/month. Considering these northern-most localities to be flukes and the Lake George area to be a more realistic limit, then the net movement was ca. 330 km and the dispersal rate was ca. 33 km/month. This is consistent with earlier estimates in the southern part of the state. This, then, is the predicted rate of repopulation of the north by movement of more southerly populations should cold weather

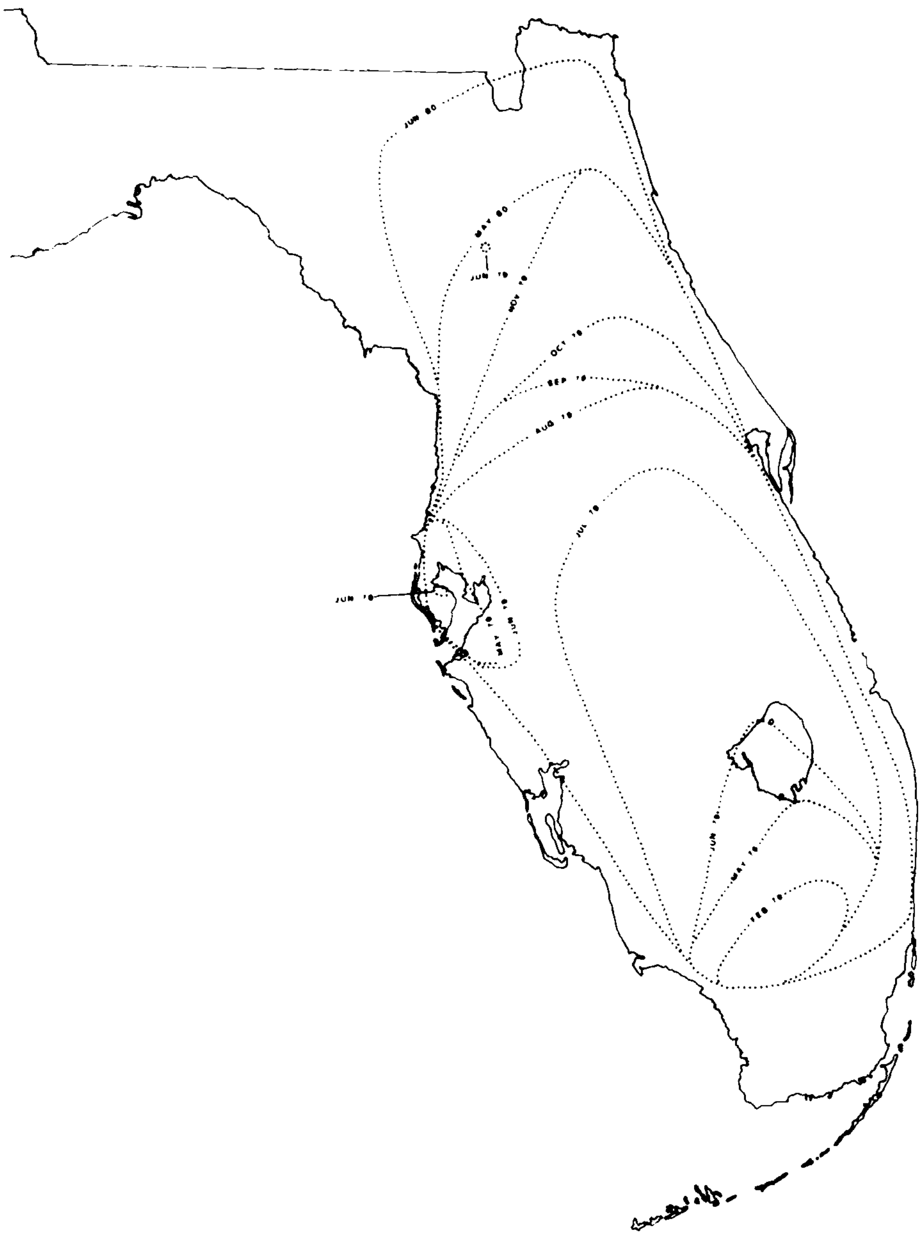

Figure 2. A map showing the approximate limits of the distribution of *Sameodes albiguttalis* at various times from February 1979 to June 1980. This represents a northward expansion of the populations at an estimated rate of 35 to 45 km/month

result in the annual extirpation of northerly populations.

Because well-established populations were not yet present in the northerly areas during the winter of 1979-80, overwintering studies were not initiated. In one area, however, it has been established that a population persisted through a late freeze (early March 1979) where the temperature fell to -8°C. Several well-established populations are now available in north Florida and these will be studied during the winter of 1980-81 to determine if they are able to persist in their present locations.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Domestic Survey for Invertebrates on Eurasian Watermilfoil and Hydrilla

by

Joseph K. Balciunas*

Objectives

The aquatic invertebrate fauna associated with submersed aquatic weeds in the United States is very poorly known and their impact on the submersed weeds is even more poorly understood. Hydrilla (*Hydrilla verticillata*) and Eurasian watermilfoil (*Myriophyllum spicatum*) are the two most troublesome submersed aquatic weeds in the United States. Before an effective program of foreign exploration for potential biological control agents on these weeds can begin, a list of insects already found on these weeds in the United States is highly desirable. It is especially important to know which of these United States insect species are actually damaging these weeds. This will not only help avoid the wasted effort in beginning importation procedures for species already present in the United States, but will also indicate which foreign taxa are most likely to contain potential biocontrol agents.

The objectives of this project were threefold. The first objective was to collect insects on hydrilla and Eurasian watermilfoil throughout their United States ranges and them to compile a list of species associated with these weeds. The second objective was to determine which of these insect species are damaging hydrilla or Eurasian watermilfoil. The third objective was to try to determine how seasonal variations in weed biomass and environmental factors affect the population levels of the aquatic insects associated with these aquatic weeds.

Approach

Collections of Eurasian watermilfoil and hydrilla were made at infestations throughout the United States and water temperature, depth, salinity, conductivity, and transparency at the collecting site were noted. At the laboratory the samples were searched under a dissecting microscope, and all the fauna was removed and subsequently identified. The amount of damage to the plant and the wet and dry plant weights were

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also recorded. One milfoil infestation and seven hydrilla infestations, all located in Florida, were sampled monthly on a quantitative basis using a specially designed quantitative sampler. Determination of whether a particular species was causing damage to the weed was based on records in the literature, on field observations, and on laboratory tests.

Current Status

During the past 2.5 years, 69 collections of Eurasian watermilfoil were made in 11 states (Figure 1). During this time, 289 collections of hydrilla were also made, mostly in Florida, although infestations in California, Texas, Louisiana, and Georgia were also sampled. All of the milfoil collections were processed, the insects identified, and a final report listing all the insect species found associated with this weed was prepared. All but 50 of the hydrilla collections have now been processed and most of the insects have been identified. A report on the insects associated with hydrilla and the results of the quantitative studies of these insect populations is now being prepared.

Plans for beginning the foreign survey for insects that have

Figure 1. Eurasian watermilfoil collection sites. Circles indicate approximate location where Eurasian watermilfoil and associated fauna were collected

potential as biological control agents of hydrilla are now being finalized. The survey will be concentrated in southern Asia with several months of collecting in each country. The countries currently slated for surveys are Indonesia, India, Thailand, Malaysia, and possibly Burma.

Significant Accomplishments

Insect collections

Snails were the most frequently encountered macrofauna associated with both hydrilla and Eurasian watermilfoil. The snails were present in most collections; in some spring runs, density was almost 2000 snails per square surface metre of hydrilla. However, most of these snails appeared to be grazing on the epiflora associated with these plants and may, perhaps, enhance the growth of these weeds by keeping the photosynthesizing surfaces clean. While a few specimens of a species that does feed on macrophytes were found, they were rare in the collections.

The insect group most frequently encountered in different collections was the damselflies, Zygoptera. While a variety of species of damselflies was represented in the collections, all damselflies are predacious on other aquatic fauna and do not directly impact on submersed weeds.

The larvae of midges (Diptera: Chironomidae) were not found in as many collections as the damselflies but, when found, were often extremely abundant and, on the basis of sheer numbers, constituted the most abundant insect group. Most species used the plants simply as a substrate on which to build their larval tubes. Most Chironomidae feed on organic detritus and plankton. Some species constructed tunnels in the stems of these weeds, but this appeared to have little effect on the plants except when chironomid populations were extremely high. However, pathogen infections associated with these tunnels were observed and may be of importance in controlling these weeds.

The larvae of caddisflies (Trichoptera) were fairly numerous and many different species were found in the collection. The feeding habits of these species were varied. Most were plankton or detritus feeders but some predacious species were also found. Several caddisfly species which feed directly on these weeds were also found. However, the population levels observed in the field of the latter species did not seem to cause noticeable damage to the plants and probably did not have a significant impact.

On both Eurasian watermilfoil and hydrilla, the greatest damage was caused by the larvae of aquatic moths of the subfamily Nymphulinae (Lepedoptera: Pyralidae). Milfoil from New York and Wisconsin was damaged by *Acentria nivea* larvae, while hydrilla was damaged, sometimes extensively, by the larvae of *Parapoynx diminutalis*, which is presently known in the United States only from Florida. The larvae of another

moth species, *Synclita obliteralis*, were found in many southern states, feeding on both Eurasian watermilfoil and hydrilla.

Other aquatic insect groups, while not abundant, were fairly frequently encountered. These were the mayflies (Ephemeroptera) and various members of the order Hemiptera. None of these was thought to be directly impacting these aquatic weeds. Three species of weevils (Coleoptera: Curculioridae) that feed on the flowering portions of Eurasian watermilfoil were collected. Most were rarely collected, although one of these, *Perenthis vestitus*, was occasionally locally abundant. Since sexual reproduction by Eurasian watermilfoil is not considered to be significant at established infestations, the impact of feeding by weevils is considered to be minimal.

Quantitative studies

A sampler for obtaining a quantitative sample of submersed weed biomass and of the fauna found inhabiting the weed was designed and constructed. This sampler has been successfully used for over 2 years in the quantitative aspects of this present study.

The quantitative studies revealed some interesting trends. Eurasian watermilfoil biomass peaked earlier in the year (Figure 2) than that of hydrilla (Figure 3). Snail populations seemed to respond to the amount of weed biomass present, while insect levels appeared to be more seasonal. The great number of insects, at times over $2500/m^2$, on the hydrilla at Lake Lochloosa, consisted almost entirely of a single chironomid species, *Glyptotendipes* sp. The population levels of snails and insects at some other infestations were more similar to those depicted for Eurasian watermilfoil. However, at the hydrilla infestation at Wacissa River, a large spring-fed stream in North Florida, snail populations sometimes approached 2000 snails/m^2 while insect densities were usually less than 10 insects/m^2.

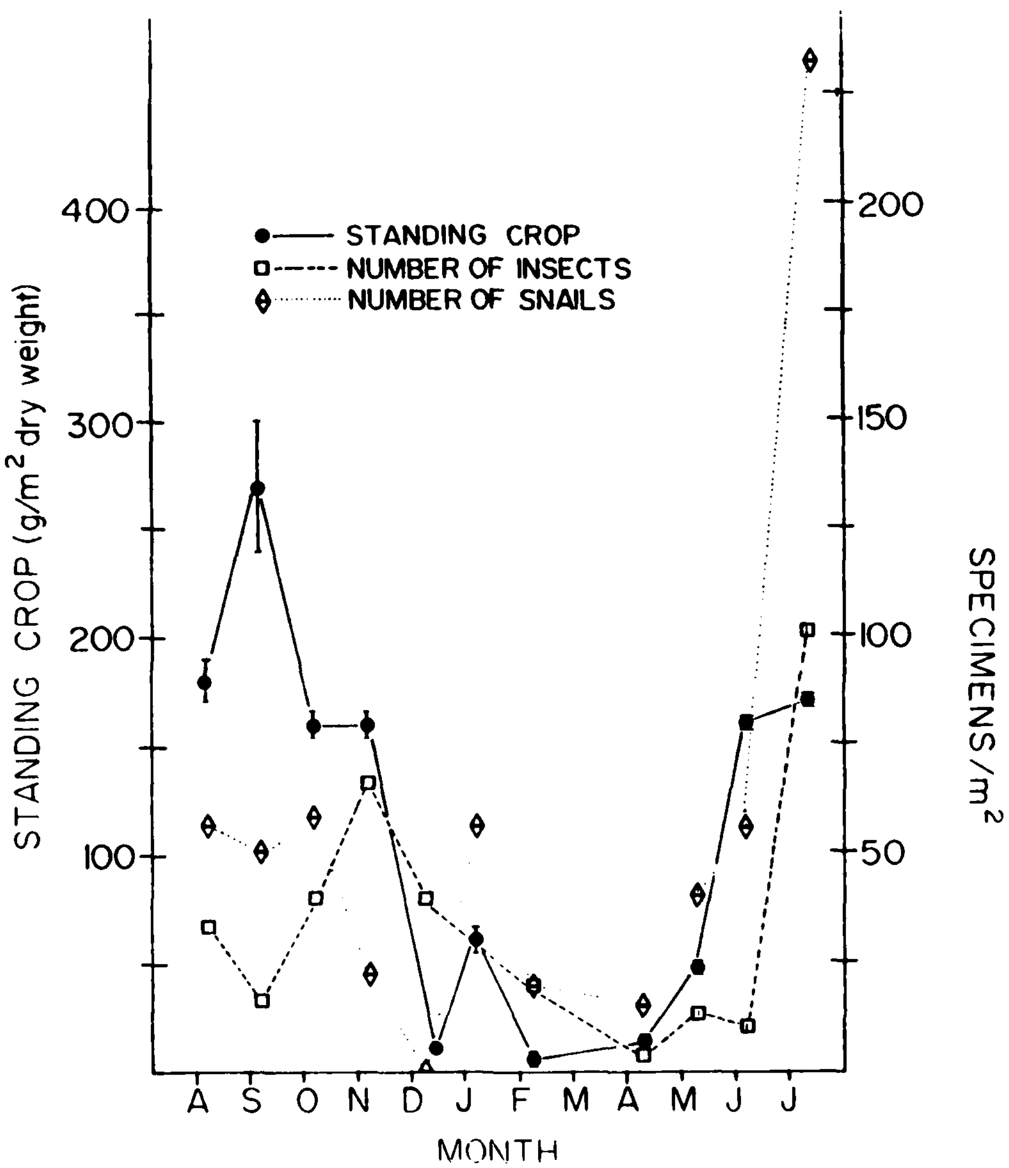

Figure 2. Seasonal fluctuations in the standing crop of Eurasian watermilfoil and the population levels of its associated fauna at Crystal River, Florida. The height of the bar on the circles indicates the standard error for the dry weight for the five samples which comprised each monthly collection. The standard errors for the population levels of insects and snails are not shown, but, in general, these were larger than those depicted for the standing crop

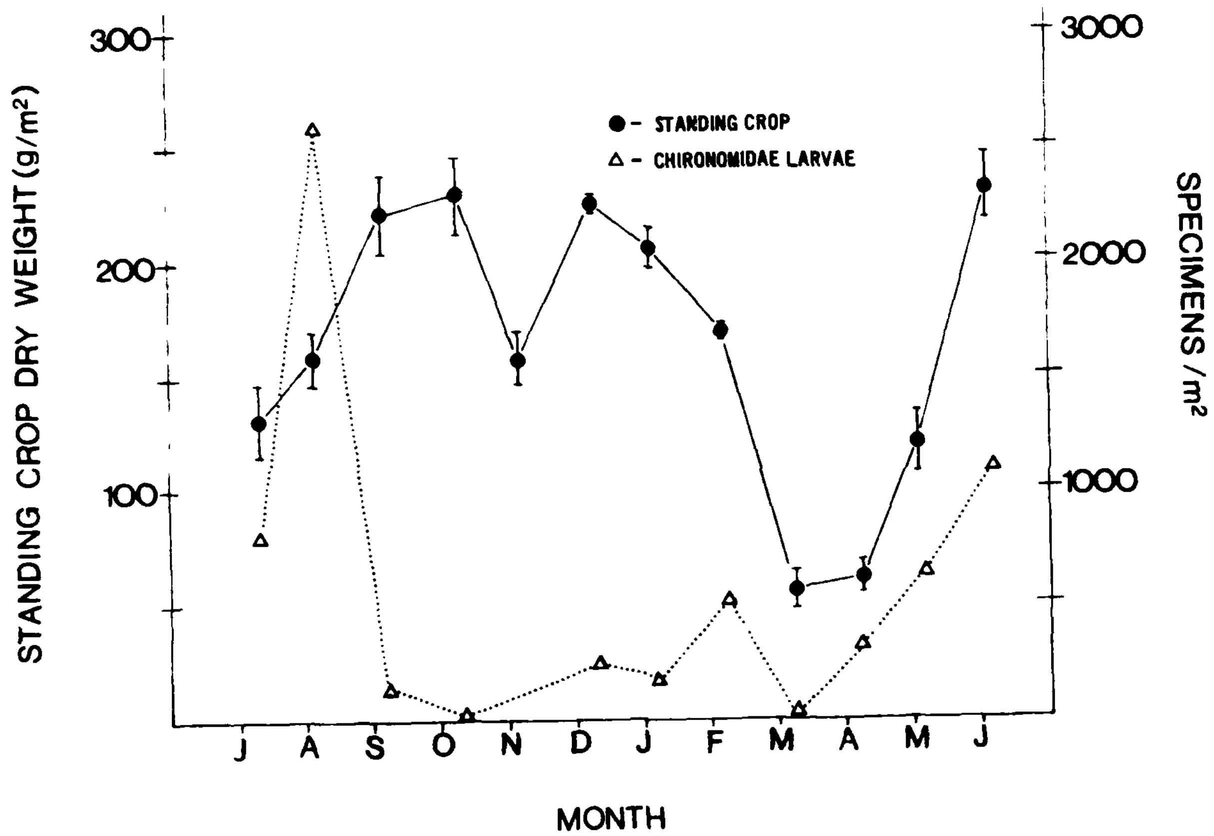

Figure 3. Seasonal fluctuations in the standing crop of hydrilla and associated fauna at Lake Lochloosa, Florida. Standard error for the five samples comprising each collection is shown by the height of the bar on each circle. Midge larvae (Diptera: Chironomidae) comprised over 95 percent of the insects collected at the site. Snail populations were too low (never over $300/m^2$) to display accurately on this same graph

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Evaluation of Insect Species for Biocontrol of Aquatic Plants

by

Gary R. Buckingham*

During this past year we have studied several species of insects as well as devoting a great deal of effort to help the Florida Department of Agriculture and Consumer Services, Division of Plant Industry, improve their facilities and capabilities for long-term quarantine testing. I would like to acknowledge their support and interest in our program which is located at their Biocontrol-Quarantine Laboratory in Gainesville.

Our program has included studies with the alligatorweed flea beetle, a watermilfoil weevil, the waterhyacinth weevil, a native moth on floating heart, and a hydrilla moth from Panama.

Alligatorweed Flea Beetle

The alligatorweed flea beetle, *Agasicles hygrophila* Selman and Vogt, was released in the United States from Argentina in 1964. It has usually provided good control of aquatic alligatorweed in Florida, Georgia, and Louisiana, but not in the colder areas like the Carolinas and northern Alabama. In 1979, I collected living beetles at the southernmost, or coldest, part of their range in Argentina with the hope that they might be more cold hardy than those introduced previously. We established a disease-free quarantine colony and, in the summer of 1979, released beetles in North and South Carolina and later in northern Alabama. The beetles were released at a total of ten sites, although secondary releases of field-collected beetles were made at other sites. At the end of July 1980, beetles were found only at one site, Snee Farms, Charleston County, South Carolina. High water and mosquito spraying possibly accounted for the failure to establish at three sites, but cold weather was probably responsible for the failure at the remaining six sites. The results are not encouraging; however, since the beetles did overwinter at Snee Farms, there is still a possibility that a cold-hardy population will develop in the future.

Watermilfoil Flower Weevil

In August 1979 we released approximately 200 male and female

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watermilfoil flower weevils, *Litodactylus leucogaster* (Marsham), at Crystal River, Florida. I reported on the biology and host specificity of this weevil at last year's meeting. Although it is native to North America, it has not been found in many of the areas invaded by Eurasian watermilfoil, including the Crystal River area. In early November last year, we recovered two male *L. leucogaster* among adults of a Florida weevil, *Perenthis vestitus* Dietz., about 2.6 km from the release site, which suggested that *L. leucogaster* had reproduced. The area was surveyed four times this year and a total of 1435 weevils were collected but all were *P. vestitus*. In addition, a total of 840 flowers, buds, and stems were examined for immatures, but again only *P. vestitus* was found. It is still too early to say that *L. leucogaster* has failed to establish since it may take several years before recovery, especially with such a small release in a large plant population. Three years is generally considered the time period necessary before conceding failure of establishment of a biocontrol agent. In addition to our studies on *L. leucogaster*, we have studied the biology of *P. vestitus*, which is apparently also specific on milfoils and is widely spread and common in North America. The biology was similar to that of *L. leucogaster*.

Waterhyacinth Weevil

The waterhyacinth weevil, *Neochetina eichhorniae* Warner, has been present in large numbers on waterhyacinth in Florida since it was released in 1973 from Argentina. A favorite collecting technique used by researchers and weed managers desiring large numbers of adults has been to pull out either the central leaf from damaged plants with young wrapper leaves or to pull out the central portion of the crown (Perkins, Lovarco, and Durden 1976; Zeiger 1979). The weevils reportedly congregated in these damaged plants and larger numbers were collected on them than were collected on undamaged plants. Del Fosse and Perkins (1977) conducted olfactometer tests in the laboratory and concluded that the broken plant produced a chemical, a kairomone, that attracted the weevils.

Since we believed that having a chemical like this might be helpful in collecting large numbers of weevils or in managing weevil populations, we attempted to develop a bioassay to isolate the chemical. When our initial crude trials failed to confirm a strong attraction of the beetles to broken plants, we studied the responses of the beetles to various stimuli hoping to design a simple system that would test for plant attractancy. We found that the beetles moved away from a moderate air flow, were attracted to both white and red light, moved downward for example if the substrate were slightly inclined, were apparently neutral to other beetles of either sex, were apparently neutral to waterhyacinth, and would flee from waterhyacinth in the presence of the researcher. These results indicated that designing a bioassay would be much harder than originally anticipated, and that possibly the beetles were not really attracted by a chemical to waterhyacinth plants, broken or unbroken.

Before continuing the experiments, we decided to repeat the published field and laboratory experiments that had stimulated our research. Following the methods of Del Fosse and Perkins (1977) as closely as possible, we were not able to confirm the strong attraction to chopped plants. Based upon the results of our experiments, I believe that the strong attraction to the chopped leaves in their experiment was probably due to a higher humidity in those containers compared to the containers with whole leaves. Another possibility, however, is that the behavioral condition of our beetles was different. Unfortunately, the experimental design of the olfactometer did not permit a decision on whether or not waterhyacinth has a subtle chemical attraction to *Neochetina*.

If broken waterhyacinth plants do not produce an attractant, why do beetles congregate in the broken plants? Observations at night with night vision goggles indicated that the broken plants were not especially attractive during the night to the beetles, but rather provided a larger hiding area when the beetles hid at dawn. When broken plants were compared only with plants that had partially open wrapper leaves that provided good hiding areas and not with all plants, there was no difference in beetle numbers. It must be emphasized, however, that these were limited observations on moderate density populations and that none of the beetle counts were close to those reported by Perkins et al. (1976).

We were initially surprised by the observation that *Neochetina* was attracted to white light in the olfactometers since they are nocturnal beetles that always appear to avoid light when disturbed during the day and since other researchers had had no success attracting them to lights placed near the waterhyacinth mats. However, shortly thereafter we found large numbers under streetlights which suggested that when the beetles are migrating they are attracted to lights. Experiments were conducted with beetles collected from several populations: (1) a heavily infested laboratory cage with badly damaged plants, (2) a lake with a heavy beetle population and heavy feeding, (3) an outdoor laboratory pool with a heavy beetle population and heavy feeding, and (4) a river with a low beetle population and little feeding. The strongest attraction to light was found in the population from the laboratory cage and the lowest attraction in the population from the river. This suggests that the beetles react either to their increasing density or to the declining condition of the plants by becoming more attractive to light and probably more migratory. Unfortunately, we did not have time to test the population that had a low attraction to light to see if it behaved more like the population reported by Del Fosse and Perkins (1977).

Floating Heart Moth

Floating heart moth, *Parapoynx seminealis* (Walker), is a small moth that attacks the leaves of floating heart, *Nymphoides aquaticum* (Walt.) Fernald. We studied this species while waiting to receive a closely related hydrilla moth from Panama. We assembled test plants and

developed techniques that will be used later with the Panama moth. *Parapoynx seminealis* was chosen because it is reportedly the only monophagous, or single host, *Parapoynx* in the United States, and we were interested in determining whether it would also be specific under laboratory conditions.

In the life cycle of this moth, the eggs are deposited along the margins on the undersides of the floating leaves and after 7 to 10 days the larvae emerge and feed as leaf miners or feed in channels eaten into the thick underside of the leaf. The newly emerged larvae have no gills, but the second instar and later instars have feathery gills along their sides. After the first instar, the larvae live in cases made by attaching to the main leaf a small piece of leaf cut from the leaf margin. Unattached cases are also made by attaching together two pieces of leaf. The larvae exit from the cases at night and feed on the leaves. After about 40 days in the laboratory, the larvae tightly close their cases and spin thin cocoons inside. The moths emerge and live about a week, during which the females deposit 200 to 450 eggs. This species can be highly destructive to the leaves of floating heart in the field. The neonate, or newly emerged, larvae have been highly specific in our laboratory tests but not completely monophagous. We have larvae developing on *Egeria densa*; however, since the experiment is not yet finished, we do not know if they will develop into adults.

Hydrilla Moth

On 5 November 1980, Dr. Joseph Balciunas hand carried a shipment of hydrilla moths, *Parapoynx rugosalis* (Walker), adults and larvae to our quarantine laboratory in Gainesville. During the coming year we will study the biology and host specificity of this species, which apparently is highly destructive to hydrilla in parts of the Panama Canal Zone. The moths are small, about 13 mm in wingspread, and are quite similar to two species already in the United States, the native *P. allionealis* and the accidentally introduced *P. diminutalis*. *Parapoynx rugosalis* females deposit their eggs on the stems and leaves of plants lying at the water surface and the neonate larvae feed by scraping the surface of the hydrilla leaves. They form small shelters by attaching a piece of leaf to a leaf. Later instars form nonattached cases from pieces of leaves. They can strip a stem by eating the leaves completely. The mature larva excavates an area in the stem where it attaches a white cocoon constructed inside the case. Air is evidently supplied to the cocoon from the stem.

Since hydrilla is not native to Panama but the moth is, the moth is obviously not specific to hydrilla. Feedings tests by Joseph Balciunas and Ted Center in Panama indicated that *Najas* might be the native host plant. We have also found that neonate larvae feed as readily on *Najas* as on hydrilla. They also feed on other plant species but these tests are just beginning and it is too early to predict the outcome.

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Development of Technology for the Mass-Rearing of *Arzama densa**

by

R. G. Baer** and P. C. Quimby, Jr.**

Possibilities of using the native insect *Arzama densa* Wlk. as a biocontrol agent against waterhyacinth, *Eichhornia crassipes* (Mart.) Solms, have been enhanced due to the development of laboratory-rearing methods. The larvae of *A. densa* feed extensively but selectively on waterhyacinth and pickerelweed (*Pontederia cordata* L.) (Vogel and Oliver 1969 a,b; Center 1975, 1976). The authors of those studies stated that "*A. densa* populations could be supplemented with laboratory-reared larvae if a satisfactory method of mass-rearing were developed." Baer and Quimby (in press) have developed an artificial diet and the technology necessary for rearing *A. densa* in the laboratory.

Improvement of the artificial diet for *A. densa* included a distilled water extract of waterhyacinth and alphacel instead of the freeze-dried waterhyacinth. This change further reduced contamination of the diet.

Due to the large consumption rate of the larvae, new diet was provided at four intervals during their 60-day larvae life cycle. These changes occurred after the 3rd, 5th, and 7th molt. At the 5th instar change, 500 larvae were placed in diet-filled trays. Previously, only 5 larvae were placed in each petri dish containing the prepared diet. One diet change was eliminated using this method.

The mating procedures involved placing adults 50:25 (♂:♀) in large cages. These cages were placed near a constant air circulation source in the greenhouse. The air movement thru the cages allowed the "calling" pheromone to dissipate resulting in a high percent of the females being mated. Previous studies show the pheromone to have an inhibitory mating effect on nearby females.

Table 1 shows the life history of *A. densa* from original collection through five laboratory generations. Almost all of the 72 field-collected larvae completed development on the diet. The sex ratio changed from 1.2:1 (♂:♀) to 1.6:1 at the 5th generation. Mean developmental time fluctuated in each laboratory generation. Several of the F_3-F_5 individuals showed an extremely short life cycle. An average of 63 percent survival was calculated from the five laboratory generations.

Fecundity data are shown in Table 2. Each field-collected female averaged 297 eggs. Average eggs/female varied throughout the five

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* This paper was not presented at the meeting due to last minute incapacitation of the author.

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laboratory generations. Perhaps, the 467 eggs/female in the F_4 generation was the result of 3:1 (♂:♀) mating ratio instead of the usual 2:1 ratio. The decrease of eggs/female compared with the field-collected females may have resulted from a low relative humidity in the mating areas.

Comparisons of pupal weights of each sex indicated that diet-fed individuals were as large or larger than those collected in the field.

In summary, *Arzama densa* can be laboratory reared for possible augmentation purposes. About 40,000 F_4 laboratory-reared (3-4 instar) larvae were provided to WES personnel for release in the waterhyacinth mat at a selected site in Norco, La.

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Table 1

Life History Data for *A. densa* Reared on Artificial Diet

Generation	Eggs Tested no.	Sex Ratio ♂ : ♀	Mean Developmental Time* (Range in Parentheses) days	Percent Survival (Egg to Adult) %
Field-collected	72**	1.2:1	--	--
F_1	150	1.3:1	83(67-112)	69.4
F_2	150	1.3:1	79(64-101)	62.1
F_3	150	1.5:1	71(39-99)	63.2
F_4	150	1.5:1	79(43-120)	59.8
F_5	150	1.6:1	65(35-104)	60.1

* Egg to adult.
** Individuals acquired as larvae.

Table 2

Fecundity Data from Field-Collected and Laboratory-Reared *A. densa*

Generation	♀♀ no.	Total Eggs no.	$\overline{X}$ Eggs/♀ no.	Percent of Eggs Eclosed %
Field-collected	28	8,314	297	95.2
F_1	21	4,736	225	97.3
F_2	181	42,061	232	93.5
F_3	200	53,643	268	94.8
F_4	54	25,248	467	96.1
F_5	290	60,348	208	88.3

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Evaluation of *Fusarium roseum* 'Culmorum' as a Biological Control for *Hydrilla verticillata*

by

R. Charudattan,* T. E. Freeman,* and R. E. Cullen*

An isolate of the fungal pathogen *Fusarium roseum* 'Culmorum' (Link & Fr.) Snyder & Hans. (hereafter called the Culmorum), which is capable of killing hydrilla (*Hydrilla verticillata* (L. fil.) Royle), was isolated from tissues of diseased *Stratiotes aloides* L. (Hydrocharitaceae) plants collected from The Netherlands. The Culmorum was capable of causing chlorosis of hydrilla shoots and rotting the entire plant, including tubers, roots, turions, and shoots. The fungus is considered to be a promising biological control for hydrilla, and this report summarizes the results of certain phases of the ongoing evaluation of the fungus.**

Host Range

Materials and methods

Pathogenicity of the Culmorum isolate to nontarget terrestrial plants was determined by germinating seeds in fungus-infested soil (preemergence trial) or by spraying fungal inoculum on young seedlings (postemergence trial). Suspensions of macroconidia (referred to hereafter as conidia) served as inoculum for both trials. In the preemergence trial, the potting soil was infested with an inoculum of approximately 3.6×10^4 conidia per gram of soil, and sown immediately with the host

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** These results have been published earlier:

Charudattan, R., and McKinney, D. E. 1977. "A *Fusarium* Disease of the Submerged Aquatic Weed, *Hydrilla verticillata*," Proc. Am. Phytopathol. Soc., Vol 4, p 222 (Abstr. S-5).

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Charudattan, R., Freeman, T. E., Cullen, R. E., and Hofmeister, F. M. 1980. "Evaluation of *Fusarium roseum* 'Culmorum' as a Biological Control for *Hydrilla verticillata*: Safety," Proc. V Int. Symp. Biol. Control of Weeds, CSIRO, Australia.

seeds. Control seeds were planted in potting soil treated with uninoculated broth medium used to grow the fungus. Percent seed germination in the controls, reduction in seed germination, and/or subsequent seedling mortality in the fungus treatments were the criteria used to determine the effect of the Culmorum on nontarget plants. Seedlings were maintained for 4 weeks following germination and observed for disease symptoms. Dead seeds, dead seedlings, or symptomatic seedlings were plated on potato dextrose agar (PDA) in an attempt to recover the causal agent.

In the postemergence trial, seedlings at the two-leaf stage were sprayed until runoff with a suspension of 10^6 conidia per millilitre, by covering the leaves, stems, and collar region. Control seedlings were sprayed with uninoculated broth medium. Seedlings maintained for 2 weeks were observed for symptoms of infection on the leaf, stem, or collar region, and sudden wilt or death. Roots were examined for damage before discarding the plants; those with symptoms were plated on PDA to recover the causal agent.

The effects of the Culmorum on six nontarget aquatic plants were determined. Actively growing shoots or entire rooted plants were maintained in sterilized tap water in suitably sized glass containers under diffused light at $25 \pm 4°C$. The fungal inoculum consisting of filtered broth suspension of conidia was mixed with the water containing the test plants to yield conidial concentrations of 12.5×10^3 to 2.5×10^5 per millilitre of the total volume. Control plants were free of the fungus. Three to five replicates per host per inoculum level were used. Following inoculation, the plants were maintained for 3 to 4 weeks and rated for damage by assigning arbitrary values of 1 to 6 to six equal zones of each replicate. The values of each replicate and of all replicates of a test species were averaged.

Results and discussion

The host range tests confirmed that the Culmorum isolate is not a virulent pathogen, but rather is an opportunistic parasite capable of depressing seed germination or inducing seedling mortality in 36 of 70 cultivars (preemergence trial). Of these, germination of 17 cultivars was reduced from 1 to 19 percent; eight, 20 to 39 percent; five, 40 to 59 percent; one, 60 to 79 percent; and five, 80 to 100 percent. However, the Culmorum isolate was recovered from diseased tissues of only 5 of these 36 cultivars. In 7 of 36 cultivars, poor seed viability, as revealed by less than 50 percent seed germination, may have rendered the plants more susceptible. In the postemergence test the Culmorum was nonpathogenic. Seven plant species in postemergence tests showed disease symptoms but did not yield the Culmorum on plating. Moreover, noninoculated controls in 4 of these plant species were also diseased, leading to the conclusion that these plants became diseased or wilted due to other causes.

The inoculum levels used in the host range trials, i.e., 3.6×10^4 conidia per gram of soil for the preemergence trial and 10^6 per millilitre for the postemergence trial, were deliberately chosen to be abnormally high. At such high inoculum levels, seedlings and weakened mature

plants are very likely to be susceptible to the Culmorum. Therefore, the results of our host range test support the conclusion that the Dutch Culmorum is indeed a parasite, but perhaps only under conditions of host immaturity and adversity.

The Culmorum was also lethal to the aquatic plants screened. At 2.5×10^5 conidia per millilitre, the Culmorum was damaging to all six nontarget aquatic plants screened. At this level, coontail, elodea, southern naiad, and spatterdock were completely killed; eelgrass was severely discolored; and alligatorweed was completely chlorotic. However, the susceptibility of these plants differed at lower levels; coontail and southern naiad, the most susceptible, were significantly damaged even at the 12.5×10^3 level. Alligatorweed, elodea, eelgrass, and spatterdock were more resistant to the fungus. These results suggest that the fungus is less damaging to some of these aquatic plants than to hydrilla, and under the test conditions the fungus was not specific to hydrilla alone.

Effect of Culmorum on Fish

Materials and methods

The effect of the fungus on the mosquito fish, *Gambusia affinis* (Baird & Girard), was tested by a static 96-hr acute toxicity bioassay. Stocks of fish from a freshwater reservoir were maintained and tested in aged tap water. They were acclimatized for at least 20 days in a 76-ℓ aquarium tank provided with aeration and filtration, and fed daily with a commercial tropical fish food. Feedings were discontinued 2 days before exposure to the Culmorum and during the test. Testing was done in 6-ℓ compartments of an 18-ℓ aquarium tank. Three such aquaria were maintained under a 12-hr day/night cycle at 25 ± 0.5°C. In six of the nine compartments, the fish were exposed to the Culmorum while the other three were the Culmorum-free controls. The test was conducted twice; the first time, three of the Culmorum-treated compartments and two controls were nonaerated while the others were aerated. The second time, all nine compartments were aerated. Five fish, each approximately 37 mm long with an average weight of 0.46 g, were placed in each compartment. A minimum of 10 fish per treatment was used. At the conclusion of these tests, a total of 45 fish had been exposed to the fungus, and 20 served as controls in the aerated treatments. In the nonaerated treatment, 15 and 10 fish were used, respectively, in the fungus and control treatments. Dissolved oxygen, pH, total alkalinity, hardness, and nitrate and nitrite levels were measured every 24 hr following initial readings, which were taken just before the fungus was added. The same parameters were also measured in the stock tank at 5- to 7-day intervals. A suspension of the Culmorum conidia in sterilized water was used as inoculum at the rate of 2.5×10^4 conidia per millilitre of treated water. The survival of the fungus at the completion of bioassay was checked by plating water samples. Records of fish mortality, disease, and behavior

during the test period were also maintained. Gills of dead fish were removed and examined microscopically for fungal conidia or mycelia.

Results and discussion

The fungus did not cause any ill effects on the test fish. In fact, the fish fed voraciously on the conidia as the fungus was being added to the water. In the nonaerated fungus treatments, four fish deaths (27 percent) were recorded. Two fish died in the aerated compartments due to malfunctioning of the aerator which resulted in low oxygen levels (<4 mg/ℓ). The fish in the properly aerated treatments showed no ill effects from the fungus.

Water temperature throughout the test remained at 25 $\pm$ 0.5°C in all compartments. Oxygen levels were close to saturation in aerated compartments, whereas in the nonaerated the levels dropped as low as 2.8 mg/ℓ. The other water quality parameters of pH, hardness, total alkalinity, and nitrate and nitrite levels were not appreciably different between treatments.

No Culmorum or other fungus was found in the dissected gills of dead fish and no lesions or other external fungal growths were observed on any of the fish. Fecal particles from the fungus-treated and control compartments gave 100 percent recovery of the Culmorum, whereas isolations from the stock tank yielded *F. solani* and *Mucor*, members of the Zoopagales and bacteria.

It is important that distinction be made between the direct and indirect effects of the Culmorum on the fish. In order to detect and evaluate lethality of the fungus, adequate dissolved oxygen must be maintained. When the oxygen was above 4.0 mg/ℓ, the fish showed no adverse effects. Therefore, the apparent high biological oxygen demand (BOD) due to the fungus in the nonaerated compartment was directly implicated in the fish kill. The effects of the fungus on BOD in larger, natural bodies of water need to be determined. But it is clear from this study that the test fish, *G. affinis*, was not directly harmed by the Culmorum.

The recovery of the Culmorum isolate from fish feces suggested the possibility of its survival after passage through the fish gut, although surface contamination of the feces by the ambient inoculum is a more likely explanation for the recovery. The recovery of the fungus from control compartments that were intended to be free of the fungus indicated cross-contamination, which probably occurred via conidia-bearing aerosol spray produced by the vigorous bubbling of air through water.

Survival of Culmorum in Water and in Soil

Water

Materials and methods. The fate of the Culmorum inoculum added to 20-ℓ glass tanks was monitored. Two tanks containing hydrilla growing

in sand and tap water were treated with the fungus at 8.4×10^4 conidia per millilitre. Hydrilla died between 14 and 21 days after treatment and a change in water quality ensued. Before and after hydrilla death, samples of water from each tank were dilution plated on PDA at weekly intervals, and the numbers of the Culmorum and other fungal and bacterial colonies were counted. Six water samples drawn at different parts of each tank were pooled and used for plating on PDA. Six replicates per dilution and four dilutions (total of 24 plates) were used to obtain average numbers of colonies.

Results and discussion. The number of colony-forming units (propagules) of the Culmorum decreased gradually from 6426 per millilitre on the 7th day to 41 per millilitre on the 70th day after the addition of conidial inoculum to water. At the same time, the proportion of other colony-forming microorganisms increased, possibly contributing to competition or antagonism towards the Culmorum. Therefore, under field conditions the Culmorum inoculum will probably decline in numbers following hydrilla death. This would lessen the danger of Culmorum damage to the more tolerant species of aquatic plants that are likely to succeed hydrilla.

Soil

Materials and methods. To determine the survival of the Culmorum isolates in soil, test tubes of sterilized sandy loam at 50 percent water saturation capacity were infested with 10^6 washed conidia per gram of soil and incubated at 10, 18, 20, 25, 30, 35, and 40°C. Six replicates per temperature were maintained. Attempts were made to recover the fungus at 2-, 3-, or 7-day intervals by plating approximately 30 mg of the soil from each tube on PDA. The survival of the fungus at these temperatures was indicated by its growth on plates.

Results and discussion. The Culmorum survived in soil under test conditions for at least 9 weeks at 18° to 30°C. The recovery of the fungus was reduced after 3 to 4 weeks, respectively, at 10° and 35°C. The fungus did not survive beyond 2 days at 40°C. A qualitative analysis of the fate of the Culmorum inoculum in soil is yet to be completed. However, the results on hand suggest that the survival of the Culmorum in terrestrial soils will be limited by temperatures of 30°C and above. Such temperatures are common in the summer in the topsoil in Florida. Moreover, propagules of *F. roseum* Culmorum are known to reside only in the top 10 cm of soil, and Culmorums in general are adapted for cool temperature. The Dutch Culmorum has a temperature optimum for in vitro growth between 19° and 21°C. Therefore, this isolate is unlikely to establish in terrestrial soils in Florida.

Influence of Some Fungicides on the Survival of the Culmorum

Materials and methods

To identify a fungicide(s) suitable for controlling the Culmorum,

seven commonly used chemical substances were screened. The fungus was mixed with wet, nonsterile sandy loam in test tubes and incubated for 3 days at 25° ± 2°C before adding aqueous preparations of fungicides. The fungicide concentrations were made in predetermined volumes of water to yield 100 percent water saturation in each tube. Ten replicates per treatment were maintained and three concentrations of the following fungicides were tested: Cis N- (trichloromethyl) thio-4-cyclohexene-1, 2-dicarboximide (common name, captan; commercial preparation used, Captan 50 percent WP); coordination product of zinc ion and ethylenebis (dithiocarbamate) manganese (mancozeb; Manzate 200, 50 percent WP); cupric sulfate (copper sulfate, 53 percent WP); manganese ethylenebis-dithiocarbamate (maneb, Manzate 80 percent WP); methyl-1-butylcarbamoyl-2-benzimidazolecarbamate (benomyl; Benlate 50 percent WP); 2-(4-thiazolyl) benzimidazole (TBZ or thiabendazole; Mertect 340 F, 42 percent E); and zinc ethylenebisdithiocarbamate (zineb; Zineb 57 percent WP). Attempts were made to recover the fungus following its exposure to these fungicides for 6 and 22 days by plating a 1:10 (w/v) aqueous dilution of the fungus-infested soil. The *Fusarium*-selective, pentachloronitrobenzene (PCNB) medium was used. The reduction in the number of the Culmorum colonies recovered from fungicide-treated soil was determined in comparison with a control without fungicides. The percent reductions were related to the lack of survival of the fungal propagules and indicated the relative efficacy of the fungicides in controlling the Culmorum.

Results and discussion

Captan and mancozeb gave significant reductions (70 to 100 percent) at both plating dates. Benomyl, TBZ, and zineb were not effective, while copper sulfate and maneb were moderately effective at the first plating. Maneb and zineb were more effective at the second plating date, while copper sulfate was not. Since the samples for platings were drawn from the same tubes for both platings, the recovery of the fungus in the subsequent plating and not in the earlier one suggests a fungistatic rather than a fungicidal activity for copper sulfate.

In view of the cost and efficacy, captan should be the preferred fungicide for control of this Culmorum. However, it must be emphasized that none of these fungicides are registered for use in water, and captan is toxic to fish. Therefore, the use of captan or other fungicides in or around water must be specifically approved.

Conclusions

It is possible to control hydrilla with an isolate of the fungus *Fusarium roseum* 'Culmorum.' The fungus can kill the entire plant and the processes of death and decay take about 2 to 3 weeks to complete. Once the fungus is applied to aquatic sites for control of hydrilla, it is expected to reside primarily on plant and animal remains in water and the surrounding soil. But the propagule numbers will decrease to a level at which the fungus is not likely to be a threat to nontarget organisms.

If necessary, the fungus can be eradicated from experimental plots by fungicides, or, more effecitvely, by general purpose sterilizers. Based on the results of this study, we feel that it is safe and desirable to test the Culmorum as a control for hydrilla in a large-scale pilot test.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Microbiological Control of Eurasian Watermilfoil

by

Haim B. Gunner*

Introduction

The classic concept of biological control has been to seek out a parasite, predator, or pathogen that can be disseminated against the pest organism and unremittingly infect or devour it. Such an approach which has had its spectacular, if sometimes transient, successes strikes us as going somewhat against the ecological grain, i.e., the original absence of such a control agent from the natural ecosystem suggests that the ecological balances are or will be tipped against it. In this light, we have been prompted to test an alternative approach to biological control based on the manipulation of microbial communities naturally associated with Eurasian watermilfoil and its immediate environment. Rather than introduce pathogenic microorganisms into the environment, we have isolated microorganisms native to the rhizosphere and rhizoplane of *Myriophyllum* spp. and by simple nutritional manipulation induced them to produce enzymes lytic to selected tissues of the plant host. Subsequent to the induction of these enzymes, the induced microorganisms are applied to the plant and pathogenesis commences. The uniqueness of this approach lies in the exploitation of an intrinsic component of the ecosystem itself. The microorganism whose pathogenicity is employed for the control of the watermilfoil is, in fact, sponsored by the rhizosphere secretions of the plant host. Our approach, to temporarily induce pathogenesis, is based on no more than the nutritional manipulation of a normally non-pathogenic, at worst potentially saprophytic, microflora whose pathogenic character ceases with the demise of its plant host. In this way, no new population is introduced into the ecosystem and no novel residues or environmental stresses accompany the control process.

Experimental

Preliminary research has indicated that there are both populations of bacteria and fungi (primarily Gram negative rods; *Cladosporium* and *Epicoccum* spp.) attached to the plants, and other bacteria (again primarily Gram negative rods) even more closely associated with the plant.

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These latter have proven extremely resistant to a variety of sterilization techniques including treatment with hypochlorite, amphyll, and streptomycin/penicillin washing and microwave sterilization. Subsequent isolations indicate that selected areas of the plant possess their own unique flora. The growing tip is dominated by a bacterium which differs from those that predominate in the decomposing tissue. From these isolates a screening was made to establish potential pathogenicity by virtue of cellulolytic pectinolytic or toxic modes of attack. Organisms were grown on agar containing cellulose or pectin as the sole source of carbon and the capacity to survive and digest these substrates was measured by zones of clearing on the plates (Figure 1) utilized as indices of cellulase or pectinase activity. Isolates showing positive activity were subsequently grown through several passages of the appropriate medium in liquid form to enhance enzyme yield. To test effective pathogenicity on *Myriophyllum* spp., five replicate shoots of *Myriophyllum* 10 cm in length were cultured in 150-ml Erlenmeyer flasks containing 50 ml of a mineral salts angiosperm growth medium; the shoots were inspected periodically for necrotic symptoms. Death was considered achieved when no further growth occurred from the growth point of the shoot section.

Results

It was first necessary to establish that the microflora intimately

Figure 1. Clearing of cellulose agar plate as a rapid screening technique for cellulose decomposers

associated with the plant did, in fact, play a role in its decomposition. As may be seen from Table 1, plants that were surface-sterilized survived one third again as long as plants that were untreated. The question remains whether this residual microflora, which clearly exercised a saprophytic effect, could, by nutritional induction, be converted, at least temporarily, to pathogenesis. A number of organisms were, in fact, isolated that gave preliminary indication of such ability as shown in Table 2. It will be noted that there is a degree of specificity in bacterial potency which reflects, presumably, an association of the microflora with respective species of *Myriophyllum*.

In Table 3 are shown the results of the application of a number of microorganisms derived from the rhizosphere of *Myriophyllum heterophyllum*. It will be noted that a significant acceleration of decomposition was achieved in their presence. These effects, however, represent the generalized attack of the native rhizosphere microflora concentrated by passage through a medium in which competing aquatic forms had been eliminated.

More telling results were achieved with a cellulolytic fungus identified as *Mycoleptodiscus terrestris* (Gerd.) Ostazeski whose cellulolytic ability was enhanced by successive passage through a medium containing cellulose as a sole source of carbon. As will be noted from Table 4, 75 percent mortality was achieved in 17 days and 100 percent mortality in 24 days.

An additional necrotic source was identified as a consortium of cyanobacteria and associated bacteria. In this case, the *Myriophyllum* species were enveloped by a veillike growth and reduced ultimately to a necrotic ball (Table 5, Figure 2). It is noteworthy that in both the application of cellulolytic fungus and the cyanobacterial cluster the enhanced effects were due to the application of the pathobiological agent. This would suggest that the flora normally inhabiting the *Myriophyllum* may exercise an enhancing saprophytic effect once a primary lesion has been effected by a pathogen.

Discussion

As the foregoing results indicate, a number of organisms have been obtained from flora associated with *Myriophyllum* spp. These organisms have essentially been induced to temporarily make the leap from saprophytic to pathogenic behavior. The entire process of inducing death in the plant tissue is clearly only partly induced by the pseudopathogen. Ancillary to its initiating role is the subsequent acceleration of necrosis by the decomposers naturally present from the plant. Though a number of active cellulose decomposers and other less defined microbial populations capable of inducing pathobiology have been identified, it is clear that these are only the results of initial screening and that perhaps other even more effective agents of control remain to be identified. In this regard, the status of the plant nutritionally, the stage in its life

Figure 2. Envelopment and compression of *Myriophyllum* spp. to necrotic pellet by cyanobacterial consortium

cycle, and its sedimentary associations must be considered in any final assessment of the efficacy of the biological control agent of choice. We are presently going forward in a program to enhance the enzyme yields of our current cellulose decomposers in concert with a sustained search for other potential pathogens as well as a study of the interactive relationship of the plant and the parameters of its growth.

Table 1

Decay of *Myriophyllum spicatum* and *Myriophyllum heterophyllum* in Angiosperm Medium

	Average Decay Time, days*	
	Untreated Plants**	Surface-Sterilized Plants†
Myriophyllum spicatum	40	60
Myriophyllum heterophyllum	25	40

* Approximate time at which 50 percent of plants were completely necrotic.
** Number of plants observed = 20.
† Number of plants observed = 10.

Table 2

Effect of Bacterial and Fungal Isolates and Cyanobacterial Consortium on Rate of Plant Decay*

	Rate of Decay**	
Inoculum	*M. spicatum*†	*M. heterophyllum*†
Cellulolytic Fungus BSF	++	++
Cyanobacterial Consortium	+	+
Fungus YBF	+	++
Bacterium PB	0	++
Bacterium Sp	0	++
Bacterium PB	0	++

* Bacteria, fungi, and cyanobacterial consortium isolated from decaying *M. spicatum* and *M. heterophyllum*.
** ++ = Average decay time significantly less than uninoculated control plants.
+ = Average decay time slightly less than uninoculated control plants.
0 = Average decay time approximately same as or greater than uninoculated control plants.
† Plants surface-sterilized.

Table 3

Accelerated Decomposition of *Myriophyllum heterophyllum* by Rhizosphere Isolates

Treatment*	Viability, days**		
	0	9	18
Control	+	+	±
Isolate K_5	+	±	-
Isolate Mixture K_1-K_7	+	±	-

* Control = *Myriophyllum* in sterile pond water.
Isolate K_5 = Myriophyllum in sterile pond water with 5 ml inoculum of isolate K_5.
Isolate Mixture K_1-K_7 = *Myriophyllum* in sterile pond water with 5 ml inoculum composed of equal parts of isolated K_1-K_7.
Isolates K_1, K_2, and K_3 showed no effect by day 9 or 18.
Isolates K_4, K_6, and K_7 showed some deterioration on day 18 but not before.
** + = alive and healthy; ± = deteriorating; - = dead.

Table 4

Effect of a Cellulolytic *Mycoleptodiscus* sp. (Strain BSF) on Decay of *Myriophyllum spicatum*

Treatment	Percent Necrotic Plants			
	Day 0	Day 10	Day 17	Day 24
Control	0	0	0	0
BSF	0	50	75	100

Table 5

Effect of a Cyanobacterial Consortium on Decay of *Myriophyllum spicatum*

Treatment	Percent Necrotic Plants Day 0	Day 10	Day 17	Day 24
Control	0	0	0	25
Cyanobacterial Consortium	0	0	100	100

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by

H. W. West*

Introduction

Mechanical control research will provide the technology base required to permit the Corps of Engineers (CE) to carry out its responsibilities in the control of aquatic plants by use of mechanical control methods and procedures. Coordination necessary to carry out this research has been taken and maintained on a continuing basis with the various Corps Districts and Divisions so that the mechanical control research of the Corps can be used operationally in a timely manner. Mechanical control of aquatic plants is addressed in OCE Mission Problem Statement No. 4-093-1 and also in new statements entitled "Aquatic Plant Control Using a Combination of Chemical, Mechanical, and Biological Methods" and "Aquatic Plant Control Using Mechanical Systems."

Objective and Technical Areas

The objective of the mechanical control research work is to develop technology and design concepts and techniques to be used to develop improved mechanical equipment and operating procedures for controlling floating, submerged, and emergent aquatic plants in Corps waterways (rivers and lakes). The research presently includes six technical work areas: (a) development of analytical models, (b) development of equipment and environmental data bases for use with the models, (c) experimental testing and evaluation of existing mechanical control equipment, (d) development of procedures and techniques for successful field deployment of mechanical control equipment, (e) evaluation of water quality effects of water disposal of mechanically processed plant material, and (f) development of design specifications for new equipment. The U. S. Army Engineer Waterways Experiment Station (WES) research will provide practical methodology for effective deployment of existing mechanical systems in terms of environmental constraints.

Documentation of FY 80 Research

Four papers have been prepared and included in these proceedings

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

that describe research in five of the six technical areas:

a. Field Tests of the Limnos Mechanical Harvesting System.

b. Prediction of Equipment Performance for Optimal Mechanical Harvesting of Submerged Aquatic Plants (Hydrilla).

c. Aquatic Disposal of Processed Hydrilla.

d. Prediction of Hydrilla Growth and Biomass for Mechanical Harvesting Operations

Work in regard to the sixth technical area (i.e. development of design specifications for new equipment) was very limited during FY 80 but will be emphasized during FY 81 and FY 82. Work under this technical area will be limited initially to the design of new plant material processing equipment, guidance equipment, and plant collection and removal systems.

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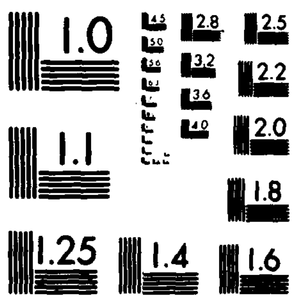
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MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

Field Tests of the Limnos Mechanical Harvesting System

by

J. L. Smith*

Harvesting System

The Limnos** mechanical harvesting system (shown diagrammatically in Figures 1 and 2) consists of a separate cutter machine, a harvester, and one or more tank barges. Plants are cut at a selected depth by the cutter machine a short distance ahead of the harvester. After the plants float to the water surface, the harvester's two gathering wheels move the floating plants into the path of the elevator/conveyor that removes the plants from the water.

Once the plants are collected on the elevator/conveyor, they are moved to the processor, a hammermill, where they are chopped into segments averaging approximately 1/4 in. in length. As the plants are passed through the hammermill, a plant slurry material is produced with a density of approximately 62 pcf. The hammermill thus reduces the volume of plant material that must be handled later during disposal operations.

If the plant material is to be transferred to a land disposal site, a tank barge is attached to the harvester. The barge collects the plant segments and the water discharged from the hammermill. Each barge is capable of storing and transporting 18 tons of plant slurry material; several barges can be included in the Limnos system. (The system tested by WES included two barges.)

Research Program and Test Areas

Test areas

The Limnos harvesting system was field tested by WES for the U. S. Army Engineer District, Jacksonville, on the Withlacoochee River in central Florida during August 1979 and again during July 1980. Additional

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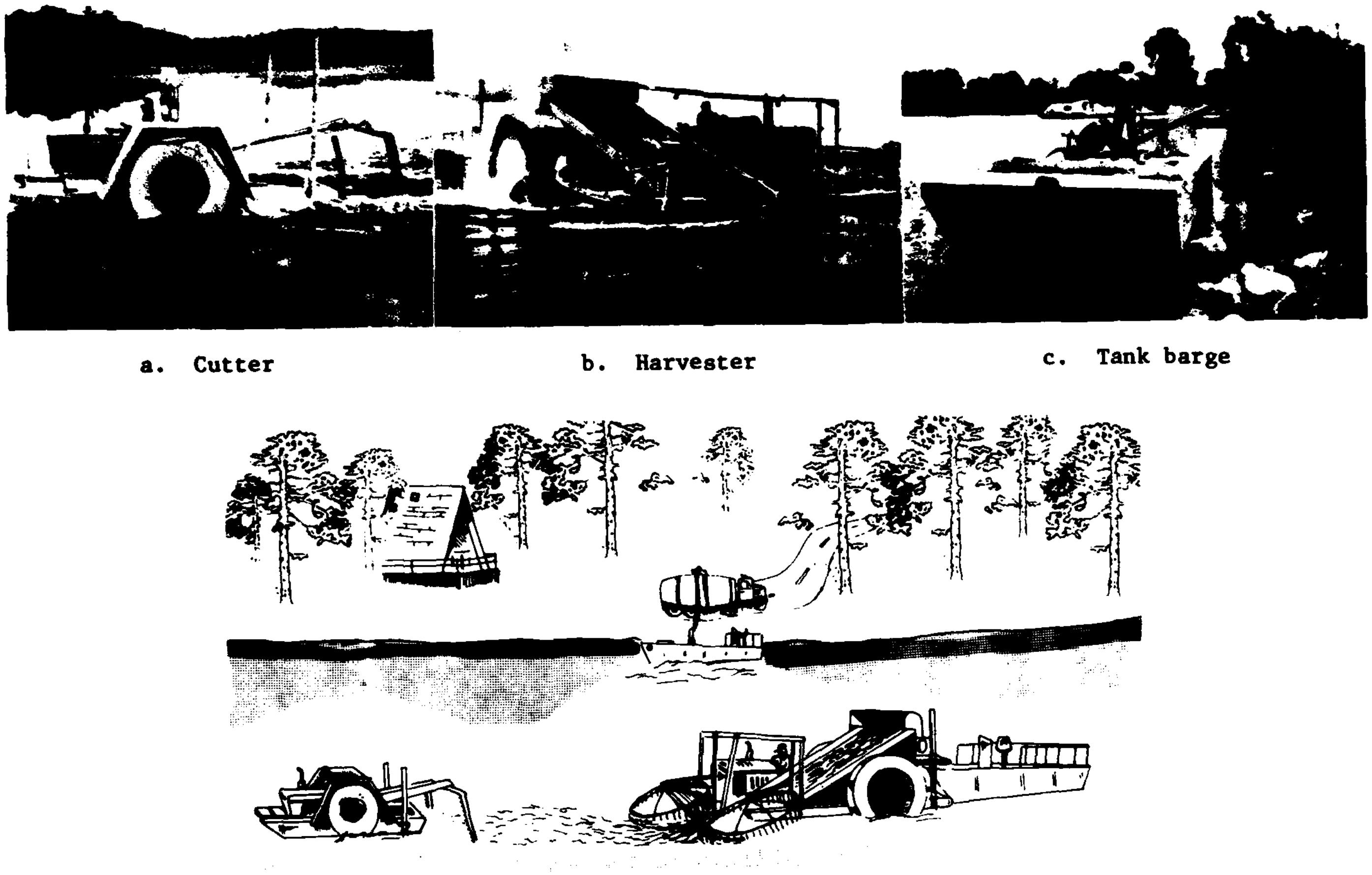
* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

** Limnos Limited, Toronto, Canada.



a. Cutter b. Harvester c. Tank barge

d. System in operation

Figure 1. Limnos harvesting system

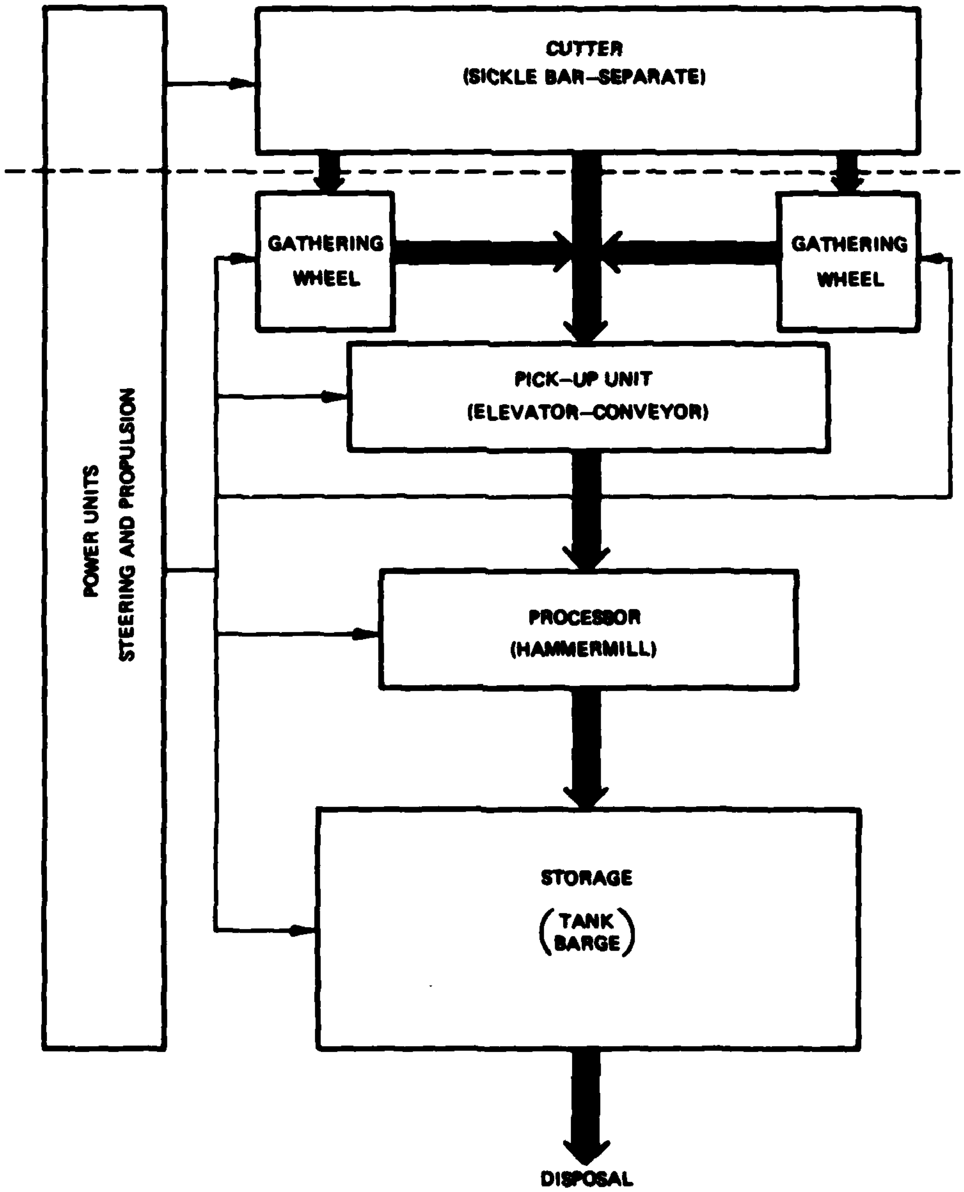


Figure 2. Functional diagram of Limnos mechanical harvesting system

tests were conducted on Orange Lake near Gainesville, Florida, during August 1980. Results of this research are described in this paper.

The predominant aquatic plant in the Withlacoochee River and Orange Lake test areas was hydrilla, although a few areas contained a mixture of hydrilla and waterhyacinth. At the time of the tests, the hydrilla was topped out and formed a matted surface.

The primary objective of the WES research was to evaluate productivity of the Limnos system in typical operating situations. The system and/or system components evaluated were:

a. Productivity o˙ the cutter machine in terms of the area covered per unit time.

b. Productivity of the cutter and harvester machines with the processed plant material being returned to the water body (without barges).

c. Productivity of the cutter, harvester, and two tank barges in removing plant material from the water body and transferring it to a land disposal site.

d. Productivity of the two tank barges.

Three additional objectives were included in the study. The first was to determine relationships between the in situ density of the aquatic plants and the operating velocities of the cutter and the harvester. These tests were necessary to provide data for the WES computer model HARVEST.

Another objective was to determine the effectiveness of the Limnos system in harvesting aquatic plants, i.e., to determine the percentage of in situ plants that were not removed from the water body during harvesting operations. However, it was not possible to measure the density of the in situ plants due to the lack of a reliable density sampling device. Therefore, these results were limited to a visual estimate of the amount of plants not removed from the site during the harvesting operation.

The final objective was to identify additional research and/or developmental work needed to improve productivity and effectiveness of the Limnos mechanical harvesting system, and other research that should be conducted to advance mechanical control technology.

Test Results

Withlacoochee River tests, 1979

The results of tests conducted during 1979 on the Withlacoochee River are summarized in Figure 3. It should be noted that the results included in this figure are based on averages of numerous tests.

Cutter productivity. The average productivity of the cutter machine was 4.26 acres/hr with an average forward speed of 1.95 mph (Figure 3). Based on total amount of plants removed by the harvester and collected in the attached tank barge, the average plant density for the site was estimated to be 16 tons/acre. A wide range of plant densities did not appear to affect the average cutter velocity.

Cutter and harvester productivity. Cutter and harvester productivity with processed plant material returned to the water body was dependent on the harvester operating or pickup width. Referring to the second set of bars in Figure 3, the average productivity of the harvester in very dense plants (greater than 16 tons/acre), utilizing its full 18-ft pickup width, was only 0.97 acres/hr with an average forward speed of 0.44 mph. When the harvester pickup width was reduced to 6 ft (see third set of bars in Figure 3), productivity was 1.45 acres/hr with an average forward speed of 1.97 mph.

Several factors contributed to increased productivity with the 6-ft pickup width. First, operational difficulties associated with the gathering wheels were reduced. In turn, material was fed to the elevator/conveyor and into the processor more uniformly. This reduced downtime required to clear material caught on the front edge of the elevator/conveyor or at the inlet to the processor. Finally, the plant density was less in the 6-ft pickup width area than in the area where the 18-ft pickup width was used.

Cutter, harvester, and tank barge productivity. The average production rate using the full 18-ft pickup width of the harvester was 1.79 acres/hr with an average forward velocity of 0.82 mph. Based on the quantity of material accumulated in the tank barges, the in situ plant density in the site was estimated to be very low (less than 4 tons/acre).

Tests were also conducted using a pickup width of 6 ft. The productivity averaged 1.0 acre/hr with an average speed of 1.37 mph. Based on the quantity of plants removed, the in situ plant density was high (approximately 16 tons/acre). The average forward speed increased with the 6-ft pickup width due to a reduction in problems with the gathering wheels. However, areal capacity and productivity decreased because of the increased plant density.

The productivity of the harvesting system was not significantly affected by use of an attached barge. The variability shown in Figure 3 can be attributed to variations in the density of plants and operating difficulties caused by the gathering wheels.

Tank barge productivity. When the barges were used with the harvester, the average amount of slurry material collected in the barge was 9.1 tons and the average time required for the round trip from the harvester to shore with unloading was 0.8 hr. Material was unloaded from the barge with the pump at an average rate of 18.1 tons/hr, and the overall productivity of each barge was 14.5 tons/hr. Larger barge loads would have increased productivity; however, it was not always possible

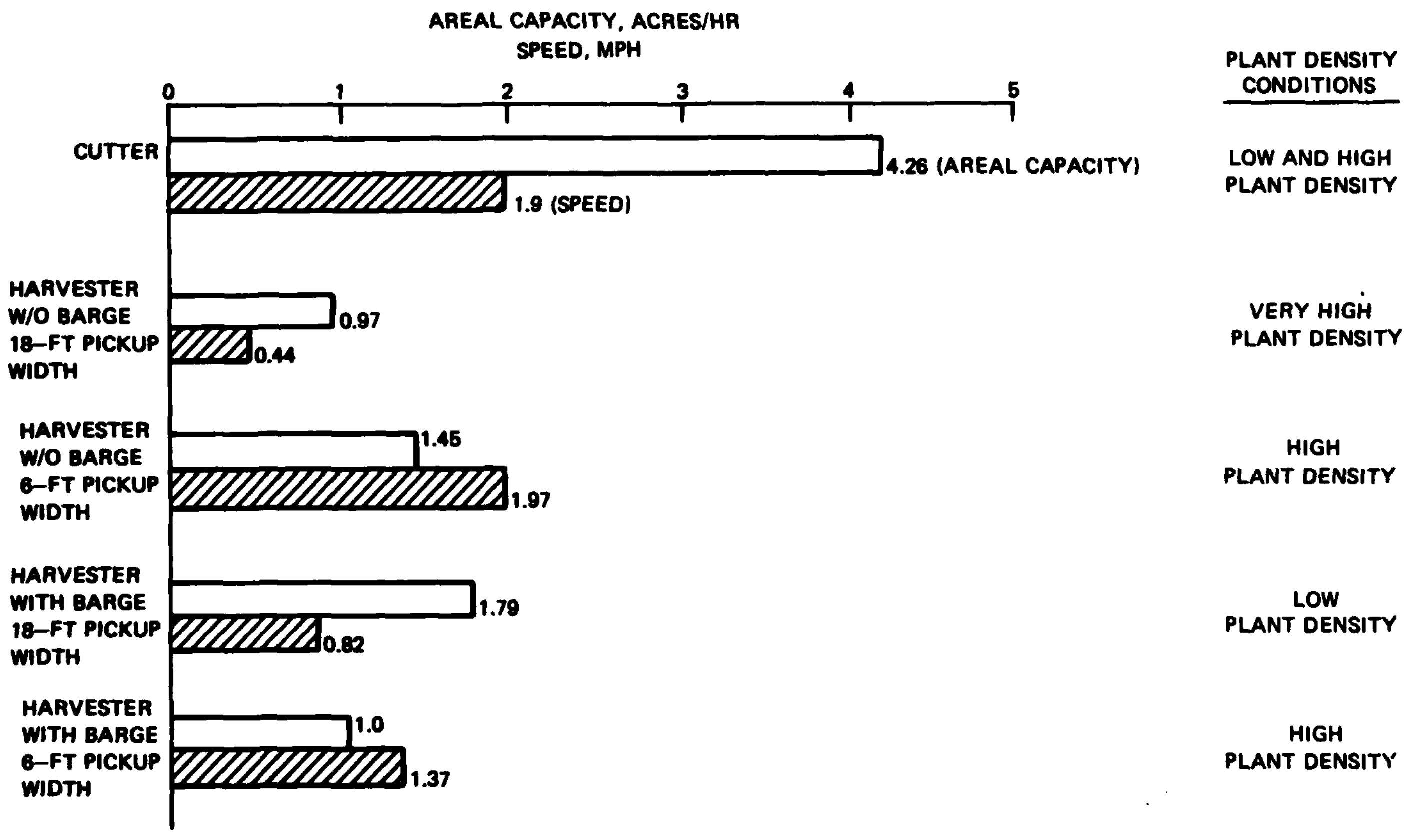


Figure 3. Areal capacity and speed of Limnos system for various operating modes and plant conditions

to fill the barges to capacity due to relatively shallow river depths (3 to 5 ft) and numerous underwater obstructions.

Total time for each barge trip was not significantly affected by travel distance when the one-way trip was less than 1200 yd. Travel speed was normally dependent on travel distance, and thus the total round trip time was primarily dependent on tasks (pumping, docking, etc.) having fixed time requirements.

Removal efficiency of the harvesting system. The estimated efficiency of the Limnos system in removing in situ plants from the water body was over 90 percent. This estimate was based on visual observations of plants remaining in and around the harvest site.

Withlacoochee River tests, 1980

The primary purpose of this series of tests was to obtain specific data required for the WES computer model HARVEST.

Results of some of the tests conducted in the Withlacoochee River during 1980 are shown in Figures 4-6. As expected, harvester throughput (i.e., plant material harvested, passed through the hammermill, and deposited in attached tank barge) increased with increased forward speed. This trend is shown in Figure 4.

The average forward speed of the harvester and cutter for various transmission gears is shown in Figure 5. The speed of the cutter, as expected, was more sensitive to transmission gear selection because of its lighter weight and reduced drag.

The time to unload a barge using the slurry pump is shown in Figure 6 as a function of the weight of material in the barge. The average pumping time ranged between 11 and 25 min, and the pumping time increased with increased barge loads. During the unloading operation, water was added to move the chopped plant material to the pump. This procedure resulted in the need to remove more material than indicated by the barge load.

Orange Lake tests, 1980

Tests conducted in Orange Lake, Florida, provided data on the Limnos system when operating in extremely dense, topped-out hydrilla. The estimated in situ plant density was 36 tons/acre (approximately 30 tons/acre harvested with estimated 20 percent loss), a much higher density than encountered on the Withlacoochee River. Also, the hydrilla plants were observed to be growing both laterally and vertically in the water column.

After conducting several preliminary tests for the crew to gain experience, the cutter forward speed averaged 2.06 mph, and the harvester averaged 1.2 mph using a pickup width of 12 ft. Based on these tests, the average throughput of the harvesting operation was approximately 27.6 tons/hr. Areal productivity values were not reliable for either the cutter or harvester due to difficulties in maintaining a constant harvesting width in the very dense hydrilla plants.

Two complete passes were required through each test plot to remove

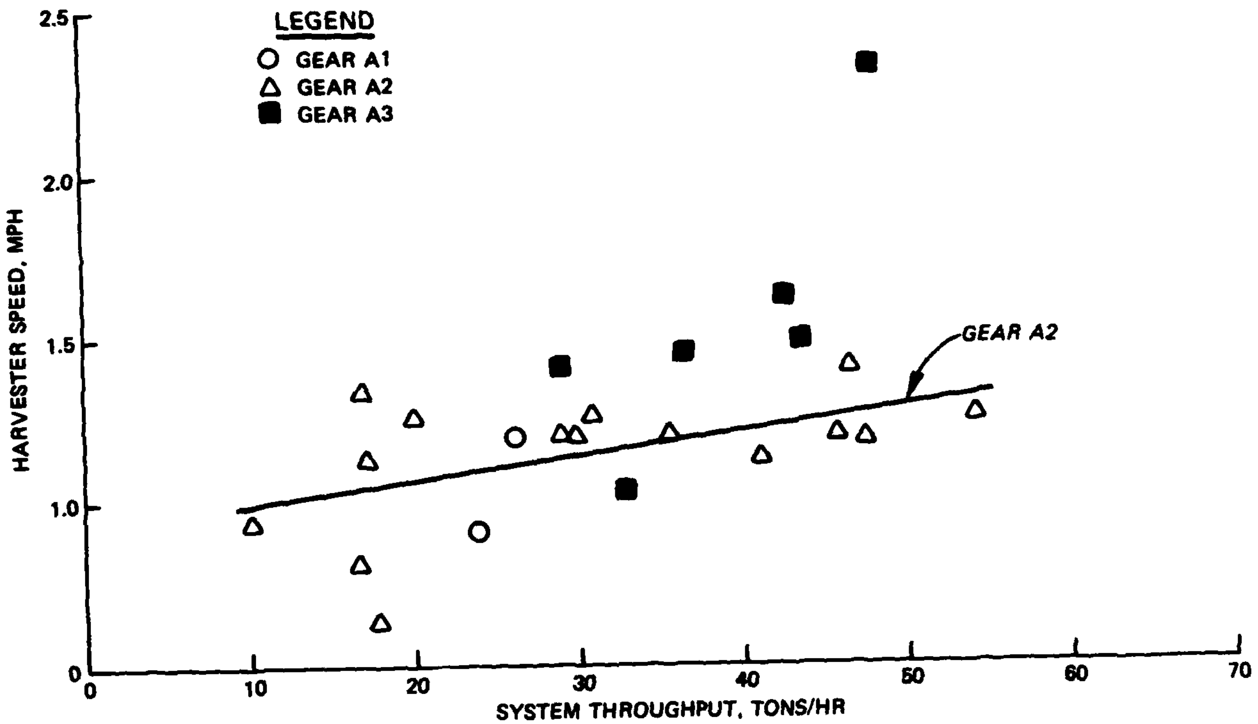


Figure 4. Plant throughput versus speed for different gears on the Limnos harvester, Withlacoochee River, 1980

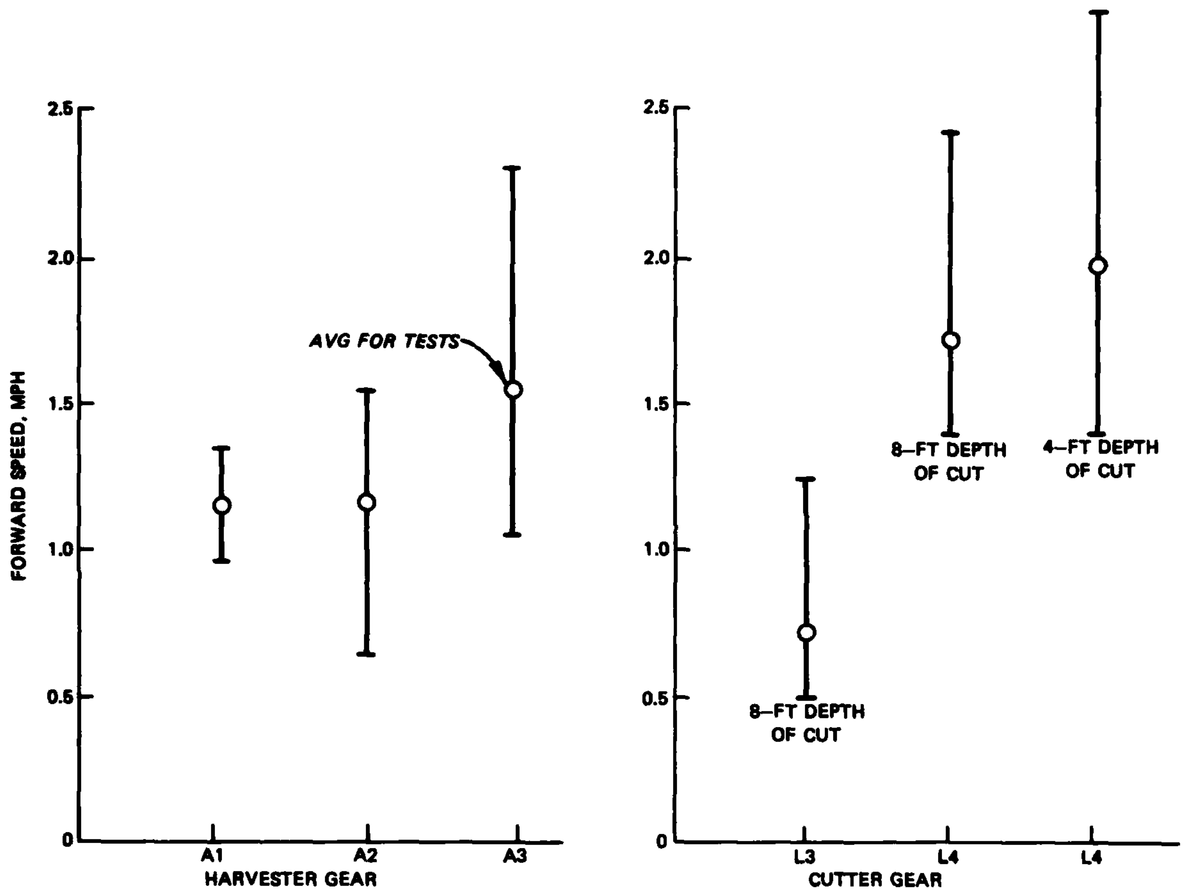


Figure 5. Range of forward speed and average forward speed for selected gears of the Limnos harvester and cutter

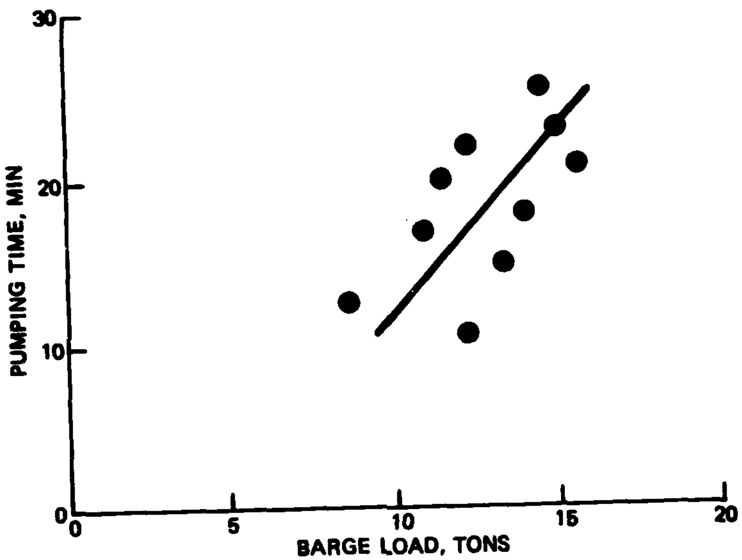


Figure 6. Time to unload tank barge containing plant slurry material

the hydrilla plants. Typically, two barge loads were obtained on the first pass through a plot (1.43 acres), and one barge load was obtained on the second pass through the plot. The average barge load was 14.1 tons and an average of 44.3 tons of material was removed from each plot. It was estimated that approximately 20 percent of the plants were missed by the Limnos system during the harvesting operation. This was primarily a result of plants not floating to the water surface.

Discussion of Machine Performance

A major component of the research involved visual observations of each machine, and identification of various functions and/or potential improvements in mechanical components within each machine. Factors considered were operator capabilities and future material handling and processing concepts. Items or functions that could be improved on each machine are listed below:

a. Cutter machine

(1) Steering and maneuverability

(2) Cutter bar mounts and cutter speed

(3) Steering rudder

b. Harvester machine

(1) Maneuverability

(2) Gathering wheels

(3) Maximum operating depth of elevator/conveyor and gathering wheels (or harvesting depth)

(4) Processor design

c. Tank barges, material unloading features

Each of these items is discussed in the following paragraphs. Suggestions for improvements and/or for additional research and development are also included.

Cutter machine observations

The cutter machine performance was generally satisfactory, and its areal cutting capacity and forward speed did not affect the capacity of the harvester.

Steering and maneuverability. Steering and/or maneuverability of the cutter machine was difficult, particularly for inexperienced operators. Steering functions were accomplished by activating the tractor brake to stop the paddle wheel on the side towards which the turn was to be made. Due to the momentum of the machine in the water, it was necessary for the operator to anticipate turns and/or correction maneuvers in advance. Maneuverability decreased when one of the brakes became worn and improperly adjusted.

Cutter machine maneuverability could be improved by use of a

hydrostatic drive system. The hydrostatic drive would permit rapid reversal of the direction of rotation of the paddle wheels to reduce the momentum of the machine. In addition, the paddle wheels could be operated in opposite directions for rapid steering maneuvers and at different speeds for continuous steering corrections. Secondary benefits of using the hydrostatic drive would be to reduce the weight of the machine and thereby reduce fuel consumption. Also the operator station (seat) could be relocated to improve visibility of the water area and plants to be cut, and to minimize the chance of hitting underwater obstructions.

Cutter bar mounts and cutter speed. When operating the cutter in dense plants, there was a tendency for the horizontal cutter bar to swing rearward. This movement caused a buildup of plant material on the cutter bar which further increased the drag on the cutter bar and reduced the cutting efficiency. Redesign of the top mounts of the vertical arms that hold the horizontal cutter bar in position would alleviate this problem.

Steering rudder. The shape and location of the steering rudder caused floating plants to collect on the rudder which in turn pushed the in situ plants down in the water column and away from the path of the horizontal cutter bar. The problem was eliminated by removing the rudder since it was considered of minimal use in steering of the cutter machine.

Harvester machine observations

Items which caused the most problems with the Limnos harvester were machine maneuverability, the gathering wheels, shallow operating depth of elevator/conveyor, and the processor (or hammermill) design.

Maneuverability. Maneuverability problems with the harvester were similar to those discussed above for the cutter.

Gathering wheels. The primary function of the gathering wheels was to increase the areal capacity of the harvester without increasing its basic size. However, the wheels used with the Limnos harvester were not effective in gathering plants in areas of high plant densities, particularly in Orange Lake. In most tests, the plants deposited in the water near the front of the elevator/conveyor were not evenly distributed across the width of the conveyor and, as a result, the nonuniform plant load that moved up to the processor tended to overload the processor. This caused clogging of the hammermill and, in some cases, shutdowns of the harvesting operations.

The gathering wheels moved plants both laterally (perpendicular to the direction of travel) and longitudinally (parallel to the direction of travel) towards the elevator/conveyor. The circular or wheel-shaped gathering units had a continuously varying forward velocity, which depended upon the angular position of a specific point on the periphery of the wheel. Floating plants moved by the gathering wheels were thus

subjected to accelerations that caused difficulties in moving the floating plants through the water.

The gathering units should move the plants towards the path of the elevator/conveyor at a relative velocity equal but opposite to the harvester velocity, thereby producing zero absolute forward velocity of the plants in front of the elevator/conveyor.

In some cases, dense plants collected on the gathering wheels and increased the water drag on the wheels and harvester. This caused the leading edge of the gathering wheels to deflect into the water and increased the forces on the structures supporting the gathering wheels. To prevent damage to the wheels and structures, the operating forward speed and width were decreased in areas of dense plants.

Operating depth of elevator/conveyor and gathering wheels. Since the maximum operating depth of the Limnos elevator/conveyor was slightly less than 2 ft (after field modification), and the gathering wheels extended to less than 1 ft deep, it was necessary for the cut plants to float to the water surface for effective removal. In areas of very dense plants, the cut plants may not float to the surface. In this situation, cutting, collecting, and removal of plants (by the elevator/conveyor) should be accomplished using harvesting components that have approximately the same operating depth.

Processor design. The processor on the Limnos harvester was a hammermill. This device chopped the plants and produced a slurry having approximately the density of water. Power requirements for the Limnos hammermill were not considered excessive compared to similar agricultural harvesters.

Nonuniformity of the mat of plants deposited on the elevator/conveyor caused frequent plugging at the inlet to the processor. The problem increased after a center bearing was added to the hammermill to reduce vibration. A cutter (saw blade) was added to divide the mat of plants on the elevator/conveyor and to eliminate clogging around the center bearing.

The depth of the processor inlet was increased from approximately 6 in. to 16 in. This design modification reduced the plugging problem and significantly increased the overall productivity of the harvester. In tests conducted on Orange Lake, throughput of the harvester increased from approximately 35 tons/hr to 66 tons/hr (Figure 7) after the processor inlet area was increased.

Two alternative approaches related to on-board processing of aquatic plants should be studied:

a. The first alternative involves the assumption that the plants must be removed from the water. In this case, procedures for partially dewatering the processed plants should be investigated. Removing a small percentage of water would significantly reduce the volume of material being handled. It would also reduce energy requirements and thereby reduce cost.

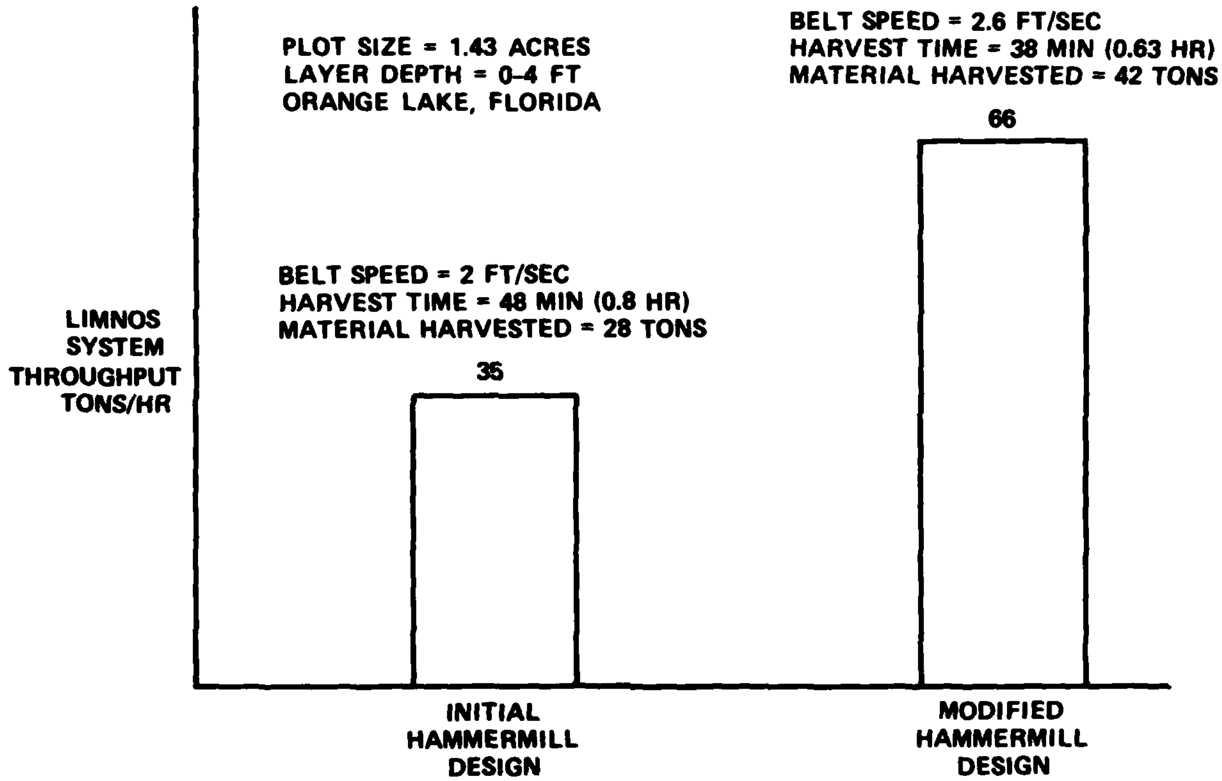


Figure 7. Effects of equipment designs on harvesting system throughput

b. The second alternative involves the hypothesis that processed plants can be returned to the water body if they are stressed to the point that they have very low probability of producing new plants. Investigation of this alternative would require analysis of the present processor and identification of other energy-efficient methods for stressing plant segments to the extent that they are rendered unviable. While considerable research is needed to develop this alternative, it would have the advantage of low energy requirements and elimination of capital and operating costs associated with barging and disposing of the plants.

Tank barge observations

Difficulties were experienced in removing the processed plant materials from the tank barges. Due to the nature of the plant-water slurry, it would not flow to the location of the pump inlet. Therefore, additional water was added to wash the material from the sides of the tank barge to the location of the pump. This increased the volume of slurry that had to be removed from the barge, which increased the time for unloading.

Two possible modifications should be studied to determine their feasibility. The first would be to alter the shape of the bottom of the barges and possibly add an auger conveyor to move the plant materials to the pump. Another possible solution would be to alter the processing unit (hammermill) so the plants could flow more easily to the pump. The most appropriate solution would depend on the type and degree of processing and would have to be determined based on the properties of the processed plant materials.

Conclusions and Recommendations

The Limnos cutter machine productivity was approximately 4.3 acres/hr with a forward speed of approximately 2 mph. The harvester machine removed and processed approximately 1.5 acres/hr with approximate forward speed of 2 mph and a processing rate of approximately 16 tons/hr with a 6-ft operating width. In very dense plants (Orange Lake) and with an operating width of 12 ft, productivity was approximately 28 tons/hr with an approximate forward speed of 1.2 mph. Use of the barges did not significantly affect productivity.

Harvester productivity generally increased with increasing forward speed. Due to drag of the harvester, changing transmission gears did not affect forward speed to the same extent as changing transmission gears on the cutter.

Tests on the Withlacoochee River, with plant densities averaging 16 tons/acre, showed that the harvester removed approximately 90 percent of the plants within the test area. In Orange Lake, with plant densities

estimated to be 36 tons/acre, the harvester removed approximately 80 percent of the plants within the test area. The processor design modifications significantly improved the performance of the Limnos system.

Further research and development in mechanical harvesting should focus on improved mechanisms for gathering plants in the water, procedures for dewatering processed plants, and identification of energy-efficient processors. If processed plant segments could be stressed to the extent they are rendered unviable and returned to the water body, barging and disposal operations could be eliminated.

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

Prediction of Equipment Performance for Optimal Mechanical Harvesting of Submerged Aquatic Plants (Hydrilla)

by

T. D. Hutto*

Introduction

Under the mechanical harvesting work area of the APCRP, emphasis is placed on the development of analytical (computer) models to aid in the evaluation and design of existing and proposed mechanical harvesting systems for controlling aquatic plants. This paper discusses the existing analytical models and a first-generation general purpose model entitled HARVEST being developed by WES.

Existing Analytical Harvesting Models

Presently, there are two analytical models that have been developed to predict performance of two specific harvesting systems: the Aqua-Trio system and the Limnos system. The Limnos Model was developed by Limnos Limited of Canada under contract to WES and was discussed at last year's annual Aquatic Plant Meeting at Lake Eufaula, Oklahoma.** The Winfrey Model was developed by Dr. Sam Winfrey and has recently been updated by Perrier and Gibson (1981).†

The updated Winfrey Model (SHAP) is a stochastic model that uses a mean plant density value and the standard deviation value together with the equipment data to predict harvesting statistics on cutting, transporting, and disposal operations for the Aqua-Trio System.

The Limnos Model is a deterministic model that also uses a mean plant density value for the site together with the equipment parameters

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

** Neil, J. H. 1980. "A Computer Model and Systems Cost Analysis of the Limnos Aquatic Plant Harvesting System," Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, Miscellaneous Paper A-80-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 157-169.

† Perrier, E. R., and Gibson, A. C. 1981 (Jul). "Simulation for Harvesting of Aquatic Plants (SHAP)," Technical Report A-81- , U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

to predict harvesting statistics for the total cutting and harvesting time (and cost).

Although both models simulate the equipment operations of the two systems, improvements are needed in both models in terms of handling and using environmental data at a high-resolution level. Also, both models assume harvester or cutter operational speeds to be constant throughout the complete harvesting operation. More realistic predictions can be made if speeds can be varied according to in situ plant densities that occur within the harvesting site.

Development of a General Purpose Mechanical Harvesting Model

The first-generation mechanical control model (HARVEST) being developed will be a simplistic deterministic model and will be prepared in FORTRAN IV language. Although initially designed to predict performance(s) for the Limnos harvesting system, which consists of a cutter unit, a harvester unit, and two transport barge units, most of the subroutines of the model are general enough to apply to other current harvesting systems such as the Aqua-Trio, Altosar, or Allied Aquatics mechanical systems.

Model inputs

Equipment inputs and characteristics. The input values for the HARVEST model (Table 1) are the maximum speeds that the individual pieces of equipment can obtain under harvesting operations. The maximum capacities and plant material throughputs control equipment operating speeds. Together, the equipment input values determine total production and production rates as a function of plant density.

Environmental parameters. Plant density determines the rate of movement of the equipment within the water body. A system operates at optimum only under ideal plant density conditions, i.e., the harvester is operating at maximum plant material throughput and as near its maximum speed as possible. The minimum allowable harvester speed is determined by water velocity and the lower limit, that when reached, causes a change in cutting widths or depths of plant material.

Other inputs. The proximity of the disposal site to the area being harvested can be critical under certain conditions, i.e., limited number of transport units, high harvester throughput system operating in dense plants, slow transport speeds, etc. The biomass density correction factor is a temporary input that will be discarded when more accurate density estimates can be obtained for certain water body infestations.

Model outputs

The model outputs are shown in Table 2. The model keeps track of all these harvesting operation components on a swath-by-swath basis through the site and the average plant density encountered for each swath being harvested.

Assumptions of the model

Although the model can be used as a management tool, a careful interpretation of the assumptions of the model (Table 3) is required.

The most important assumptions of the model are:

a. The harvesting operation is not slowed down by the cutter; i.e., the cutter can always go at least as fast as the harvester. The cutter may have to slow down or adjust its cutting width or depth so as not to cut too much plant material that would overload the harvester or permit material to float away from the path of the harvester.

b. The harvester's speed is controlled by the in situ plant density within a specified layer depth along the swath, and also by the maximum plant material throughput of the harvester. Previous models have assumed the maximum speed of the harvester and controlled the amount of material by varying only the cutting width of the plants. In the WES model, a cutter width reduction only occurs when the harvester, because of increased plant density, has been slowed to a speed below the velocity of the water or some accepted minimum value if the water body has zero current.

Logic of the model

The program logic for the overall harvesting operation is shown in Figure 1. The program first reads the equipment data base. Then, the environmental data base is accessed and the optimum harvesting condition (Option 1), which is full cutter width and full cutter depth, is evaluated. The average plant density for the swath is calculated from the density array for the maximum cutter width and depth. The harvester forward speed to maintain the maximum harvester throughput is then calculated. If the calculated speed falls between the maximum and minimum harvester speed inputs for the system, harvesting of the swath is then initiated. If this speed is greater than the maximum allowable harvester speed, the maximum speed is used for harvesting of the swath. If the harvester maximum speed controls the operation, this indicates that the aquatic plants are of a density that is too low to maintain the maximum throughput of the system even at the maximum operating speed. If the calculated speed is less than the harvester's minimum speed, then Option 2 is selected for evaluation. Option 2 allows full depth, but the cutting width of the plants can be reduced, so as to increase the speed of the harvester. If the new calculated harvester speed is above the harvester's minimum speed, the swath can be harvested. If the speed is still not acceptable, the cutting width is reduced again until either an acceptable speed is reached or the cutter width reaches an unacceptable value, which is currently assumed to be 6 ft. If this occurs, Option 3 is evaluated, which allows decreasing the depth of cutting to minimize the amount of material to be harvested within the swath and maintaining full width.

The procedure is repeated for as many swaths as necessary to

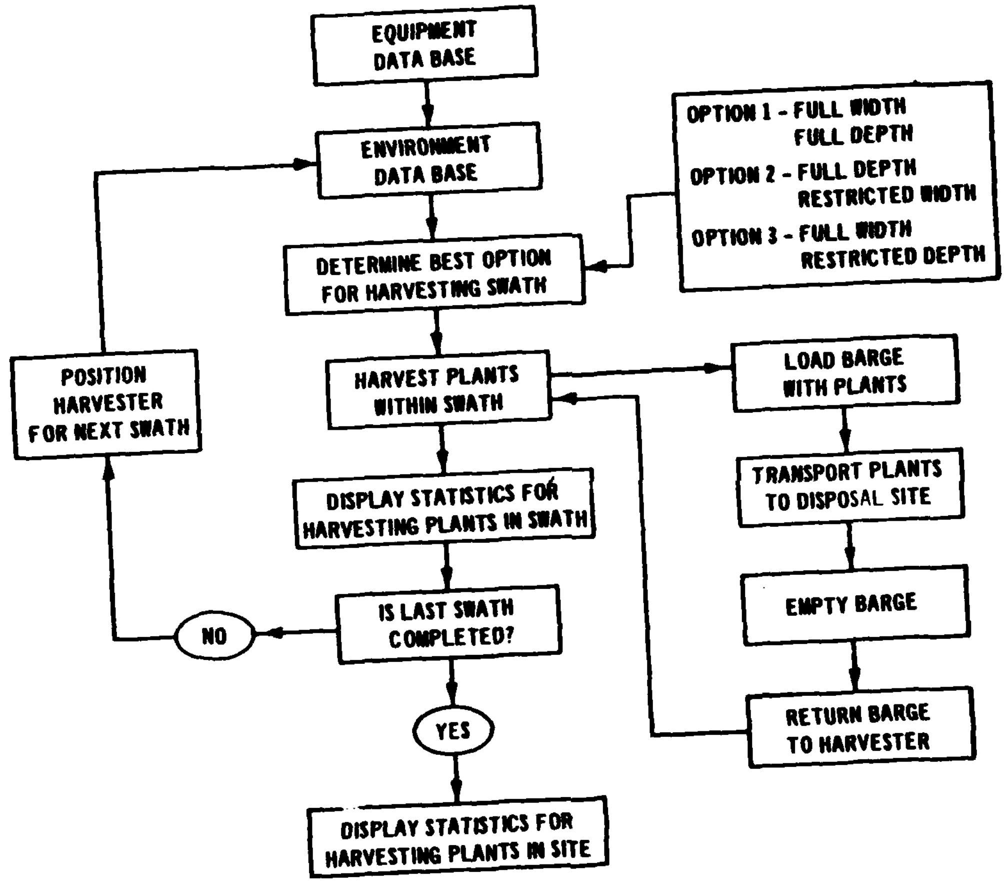


Figure 1. Generalized flowchart for HARVEST Model

harvest the plot with transport units or barges being emptied as they are filled. It is believed that adjustment of the harvester speed due to changes in in situ plant density is valid because a system cannot operate at maximum speed unless the plant density is low. It is believed that Options 2 and 3 would only be needed in predicting harvesting speeds for mechanical systems with extremely low throughput capabilities and that were operating in very dense, submerged plant stands.

Actual cutting and harvesting operations

The cutting and harvesting begins at any chosen corner of the site (Figure 2). At the end of the first swath, the harvester unit turns 180 deg, and harvesting continues along the next adjacent swath. This procedure continues until a transport barge is filled with plant material. Once filled, the harvester stops, disconnects the filled barge, and connects a new barge to the harvester. Harvesting then is reinitiated along the swath until the site is completed. Each x- and y-location where a transport barge is filled is determined from the grid array and is used to calculate transport time to and from the disposal site. Once the barge has arrived at the disposal site, it is docked and the time for unloading of the material from the barge is determined. Once unloaded, the barge then travels back to the corner of harvesting site nearest the disposal area and waits until the other barge is filled with plant material.

HARVEST Model Predictions

HARVEST has been used recently to obtain predictions for a 1000- by 220-ft site (5.05 acres) on the Withlacoochee River, Florida. Predictions were made for two sets of inputs: (1) using the plant density values as measured by WES using the Allied aquatic sampler and a maximum manufacturer's estimate throughput value of the harvester of 50 tons/hr; and (2) using plant density measurements as indicated by actual harvesting during field tests and a system throughput value of 35 tons/hr.

The plant density input data for the harvesting site were developed using a three-step procedure as follows: (1) sampling of the site with the Allied biomass sampler, (2) preparation of an areal plant density map, and (3) digitization and conversion of the map of plant density data into a grid array format for input to the HARVEST model.

The 5.05-acre site was sampled at 17 randomly selected locations (Figure 3) for a water depth layer of 0 to 2 ft from the surface. By correlating the surface area of the sampler and the weight of plants within the sampler, a density value for each location (in tons/acre) was obtained.

The areal density map (Figure 4) was prepared by using the density values from the sample locations available, photographs, and the interpreter's knowledge of the area. Fifteen density classes (in 2-tons/acre class increments) were used to delineate the area.

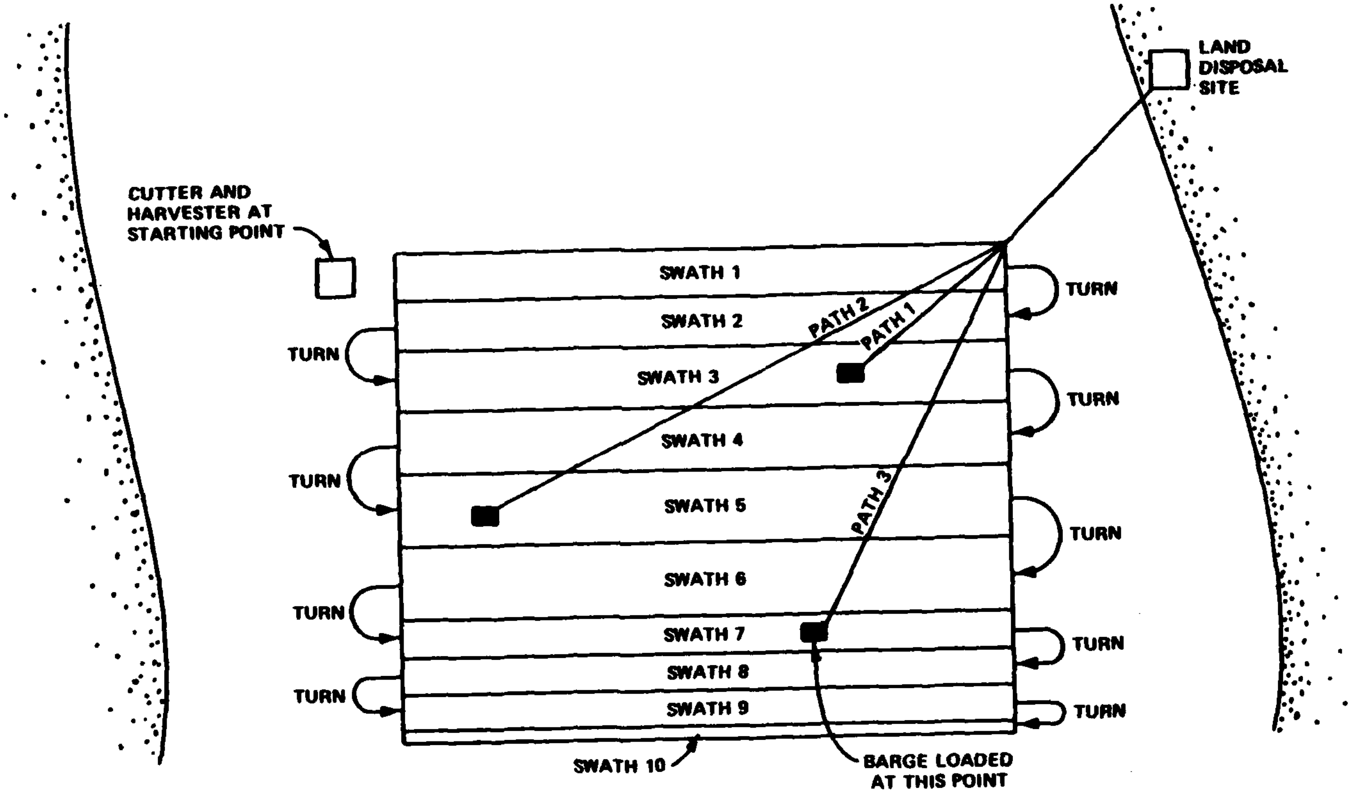


Figure 2. Sketch of cutting and harvesting simulation in HARVEST Model

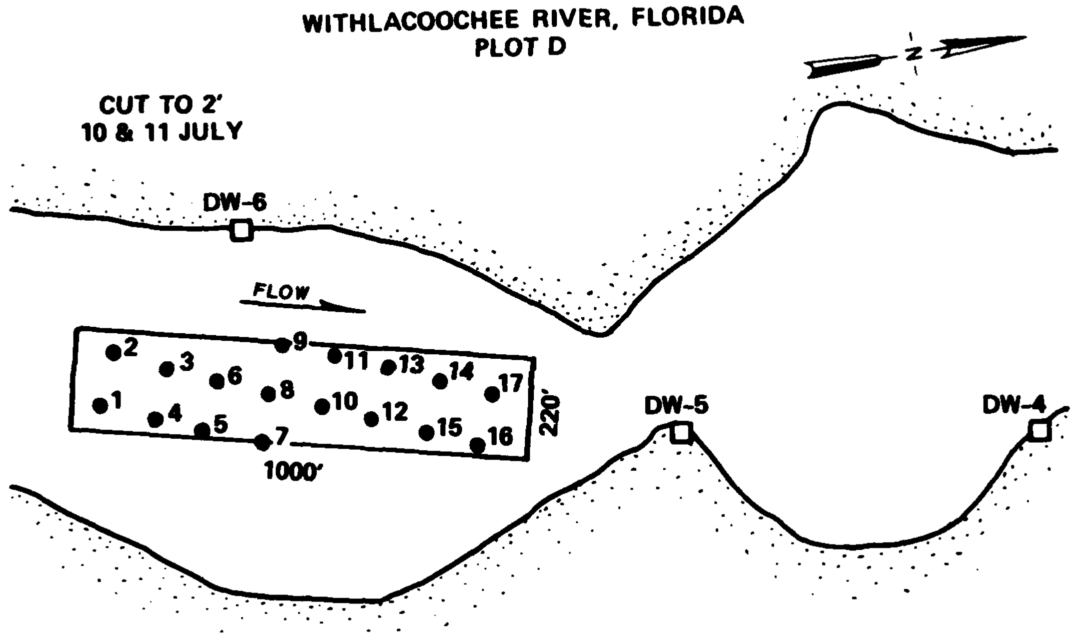
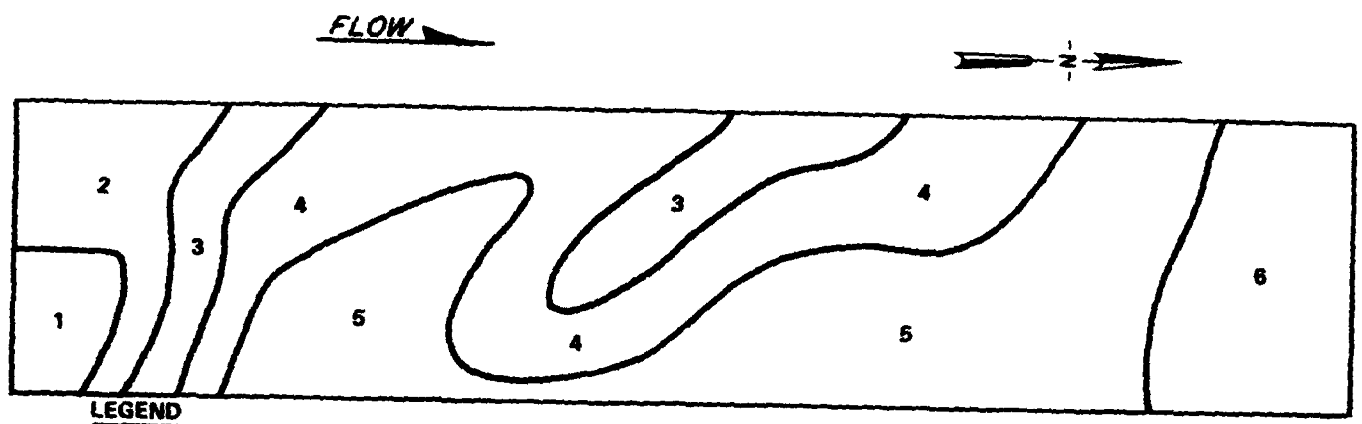


Figure 3. Biomass sample locations

WITHLACOOCHEE RIVER, FLORIDA
PLOT D (220 FT X 1000 FT) CUT 0 TO 2 FT



LEGEND

CLASS CODE	PLANT DENSITY, TONS/ACRE
1	2
2	4
3	6
4	8
5	10
6	12
7	14

Figure 4. Density relations mapped from biomass sampler data

The areal map was digitized using a conventional x- and y-coordinate graphic digitizer. These data were placed on computer disc, edited, and checked by plotting on a Calcomp drum plotter. A computer program was used to grid and fill the area with the appropriate density class value at a horizontal grid spacing of 2 ft. This grid spacing was chosen based on the equipment characteristics as being the optimum spacing. The resulting plant density grid array was a 500 grid by 110 grid.

Predictions with data input set 1

The predictions for data input set 1 (Figure 5) were obtained with the HARVEST model and then compared with the experimental data obtained from actual harvesting operations in the Withlacoochee River, Florida. Comparisons were made for harvested material weight, site harvesting time, and number of swathes needed to harvest the site. The predicted values for amount of material and harvesting time were quite low and it was determined that problems could exist with one of the following: (1) some of the assumptions used in the model might be invalid, (2) the plant density inputs might be in error, or (3) the maximum throughput of the harvester of 50 tons/hr might be in error.

The first check was to determine if the total amount of plant material harvested, as calculated by the model, 25.6 tons, reflected the density values in the density array. This check was performed by calculating from the density array, independent of the model, the total amount of material in the site. This check revealed that the model should have calculated 25.2 tons of material. Since the model calculated approximately the same amount of material, 25.6 tons, on a swath-by-swath basis, the other model predictions were assumed to be reasonable in terms of this input density data that was derived from measurements by the Allied biomass sampler.

The next check was to compare the amount of material harvested by the Limnos system, 75.0 tons, with the amount predicted by the model, 25.6 tons (Figure 6). This comparison indicated that the input density data value derived from measurements by the Allied biomass sampler was inaccurate by a factor of approximately 3 and was one of the contributions to the lack of agreement between predicted and field-measured parameters.

Since harvesting time is highly dependent upon throughput of the harvesting system, tests were conducted to determine if the value used in the predictions of 50 tons/hr was realistic. Ten swaths 1000 ft in length were harvested and the amount of material harvested was measured at the end of each swath. Harvesting times were recorded for each swath. Turning, barge changing times, etc., were not considered since a reliable number for average maximum throughput was desired. These tests revealed that although the system at times did reach throughputs of 50 tons/hr, the average throughput of the system for the 10 tests was approximately 35 tons/hr.

Predictions with data input set 2

Predictions were then obtained for data set 2, which consisted of all the input data in set 1 except for a change to the plant density

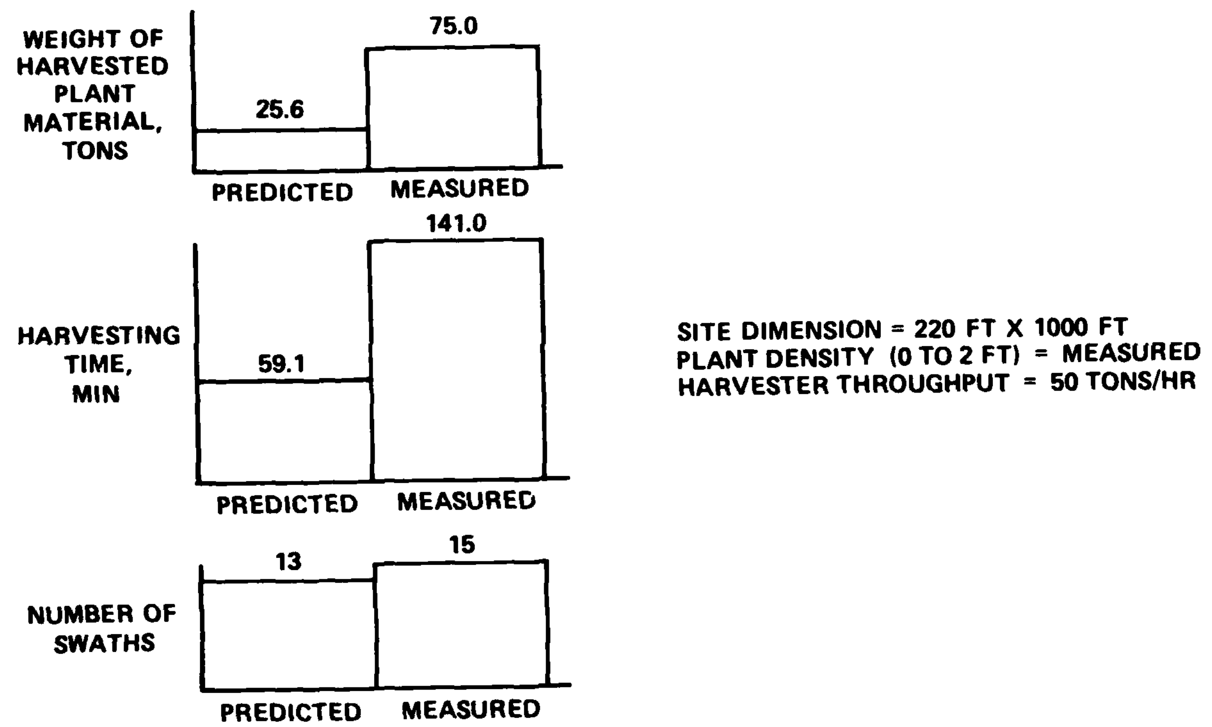


Figure 5. Predicted versus measured values, data set 1

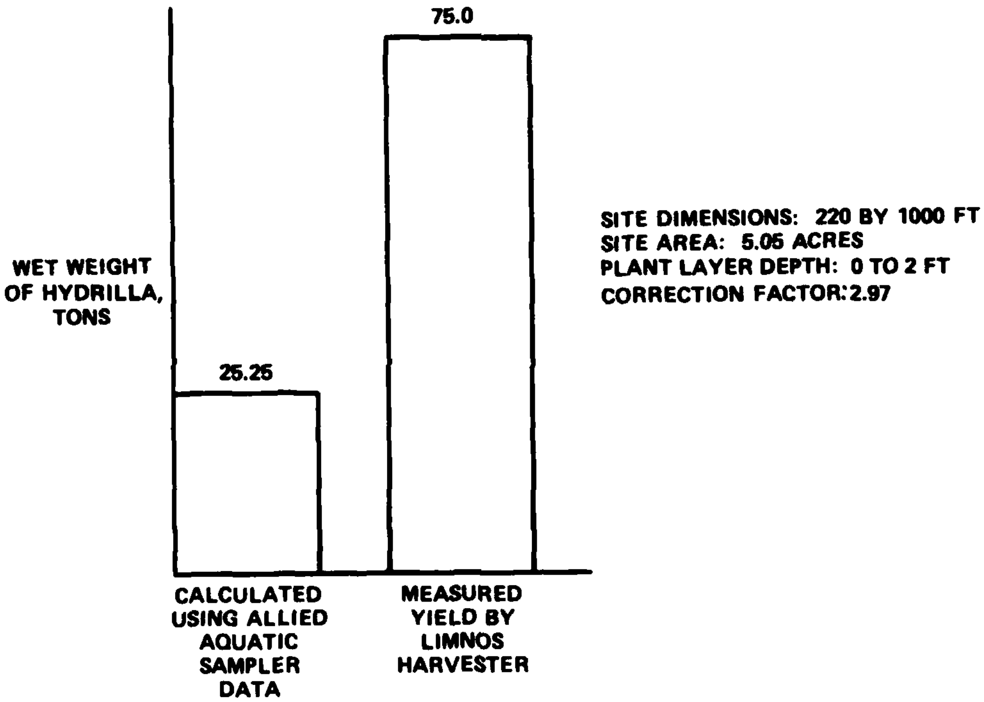


Figure 6. Calculated and measured hydrilla wet weights within site, Withlacoochee River, Florida

array and the maximum system throughput. A correction factor of 3 was used for adjusting the plant density array used in data set 1. The same areal distribution of density was assumed so each grid point density value within the data array was simply multiplied by 3 to create a new density array. The maximum system throughput value was considered to be 35 tons/hr based on the results of the tests discussed previously.

A second set of predictions was then obtained using the adjusted plant densities and a realistic maximum throughput value of 35 tons/hr (Figure 7). Comparisons now indicated very good agreement in the weight of harvested plant material, harvesting time, and number of swaths. It should be noted that the predictions for the number of harvesting swathes did not change for the two sets of inputs because the plant densities were too low to cause the cutter bar width to be reduced during the harvesting operations. Therefore, all swathes used the same cutting width for harvesting of the plants within the site.

Summary

Results of these predictions with the HARVEST model for the Limnos mechanical harvesting system indicate that the model is very sensitive to two input parameters: plant density and maximum system throughput. Therefore, data on these parameters must be available if reliable predictions of mechanical harvesting operations are to be obtained.

Plans for FY 81

Efforts in FY 81 will be directed toward the development of the overall conceptual model for mechanical control operations (Figure 8) into one of reality. It is believed, with minor modifications and additions, that the present first-generation HARVEST model can effectively provide reliable estimates of minimum harvesting times and harvesting methods for most harvesting systems currently available. With the development and addition of other submodels (for example, aquatic plant growth and biomass prediction submodel, and aquatic disposal prediction submodel), the overall HARVEST model can give the operations manager valuable information concerning when to cut and harvest, and at what water depths, for optimal mechanical control.

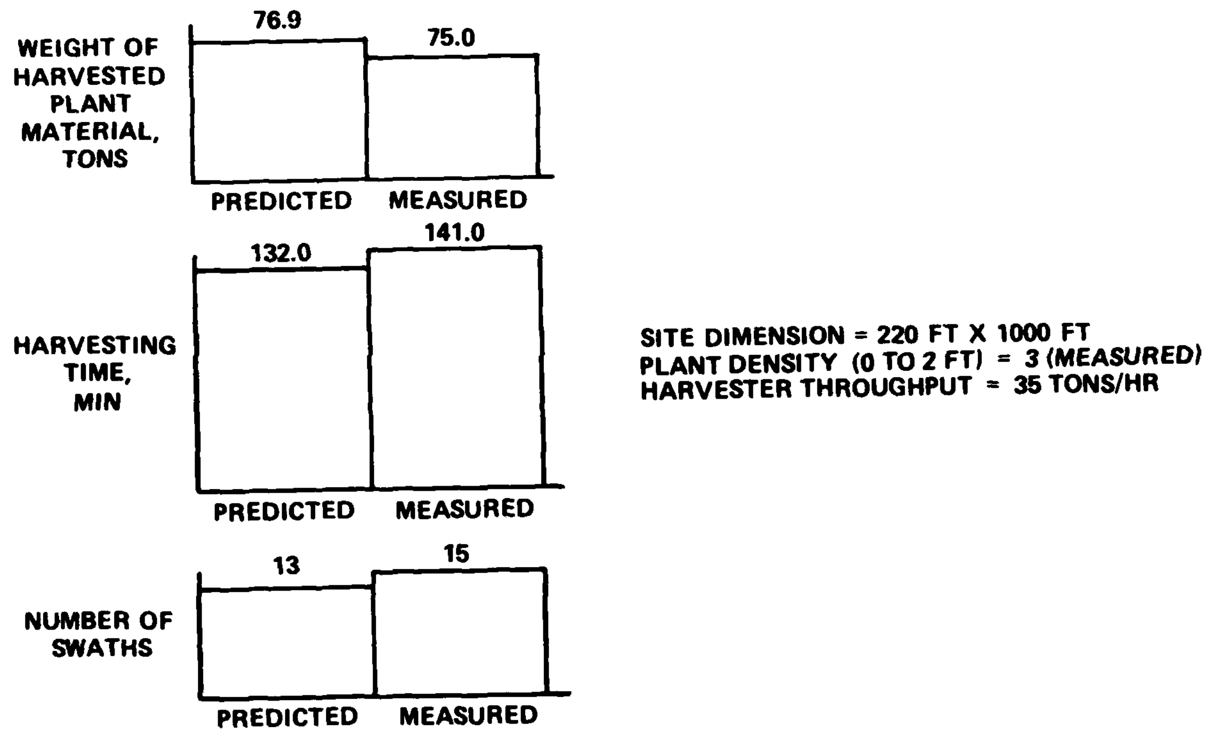
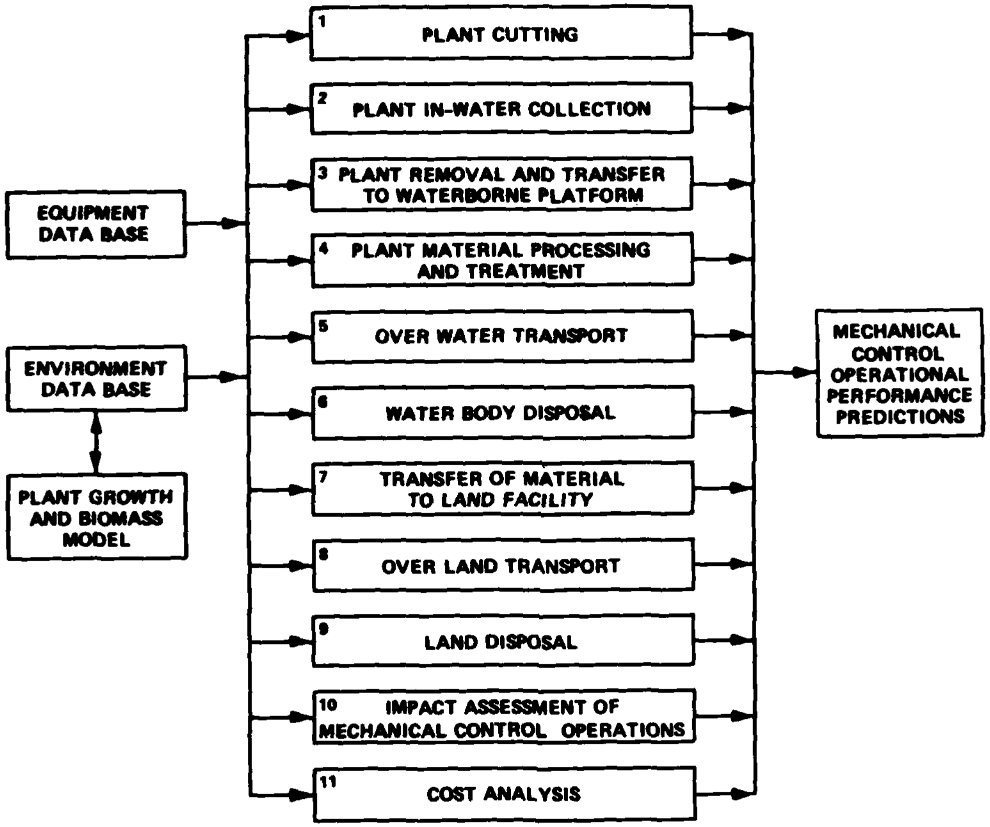


Figure 7. Predicted versus measured values, data set 2



CONCEPTUAL APCM MODEL

Figure 8. Conceptual mechanical control model

Table 1

Inputs to HARVEST Model

Equipment characteristics
Cutter width, ft
Harvester maximum speed, ft/min
Harvester throughput, tons/hr
Harvester turning time, min
Transport unit changing time, min
Transport unit capacity, tons
Transport unit speed loaded, ft/min
Transport unit speed empty, ft/min
Unloading pumping rate of transport unit, tons/min
Environmental parameters
Plant density grid array, tons/acre
Water velocity, mph
Water depth, ft
Other inputs
Distance from site corner nearest disposal site to disposal site, ft
Plot corner nearest disposal site
Correction factor by which biomass sampler densities are multiplied
Docking and setup time at disposal site, min

Table 2

Outputs of HARVEST Model

Harvester speed for each swath, ft/min
Harvester time for each swath, min
Plant material harvested for each swath, tons
x- and y-location of each filled transport unit in site
Total harvesting time, min
Total harvesting time including turning time, transport time, and disposal time, min
Time harvester is waiting for transport unit, min
Total areal production of system, acres/hr
Total material production (throughput), tons/hr
Total plant material harvested, tons

Table 3

Assumptions of HARVEST Model

The cutter unit can operate at a faster speed than the harvester, i.e., it does not slow the harvesting operation
The harvesting operation, which includes cutting, harvesting, transporting, and disposal, begins with the start of the harvester in the upper left corner of the site and ends when the last transport unit is emptied
The turning time of the harvester at the end of the swath is constant
The harvester operates at a constant speed for a particular swath. This speed is determined at the start of the swath and is based on cutter width, plant density, and maximum throughput of the harvester
The transport units are filled to their rated capacity
The transport units leave from the point at which they are filled, go through the site corner nearest the disposal site, and return through the site corner to the new location of the harvester in the site
The loaded and unloaded speeds of the transport unit are constant as is the unloading (pumping) rate
Docking and undocking times of the transport units from the harvester are constant
The minimum forward speed of the harvester is an input, normally the current velocity or 0.5 mph, whichever is lesser

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

Aquatic Disposal of Processed Hydrilla

by

Bruce Sabol*

Introduction

During the 1979 operational testing of the Limnos mechanical harvesting system, it was observed that barging the processed plant material frequently slowed the overall system operation and always increased the operational costs. At long travel distances to a land disposal site, barging could be the limiting factor controlling system operations. If barging could be eliminated as a necessary step in harvesting operations, operational costs could be cut by up to 50 percent. As a result of these observations, it was decided that the FY 80 and 81 mechanical harvesting Large-Scale Operational Management Test (LSOMT) for the Jacksonville District should include work to determine what short- and long-term water quality effects occur in a water body due to disposal of processed (chopped) plant material (principally hydrilla).

Approach

The approach to this water disposal problem is shown in Figure 1. The first-generation WES model will be limited to determining only the aquatic disposal effects within the boundary of the harvesting and disposal site (assumes no horizontal mixing). Disposal effects for other locations within the water body will hopefully be addressed in future years under the APCRP.

The WES model is presently being conceptualized and will include provisions for predicting the oxygen depletion of the water, the repropagation of processed plant material, and the total solutes released to the water during a specific harvesting and disposal operation. To obtain predictions or estimates of the above site responses, it is necessary that a prediction methodology be available that takes into account certain water body site and operational factors such as plant density, depth of cut, time of cut, and water depth. The resulting predictions will then be compared with the actual response of the water body as determined in a field test. The results of the field test will define deficiencies

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

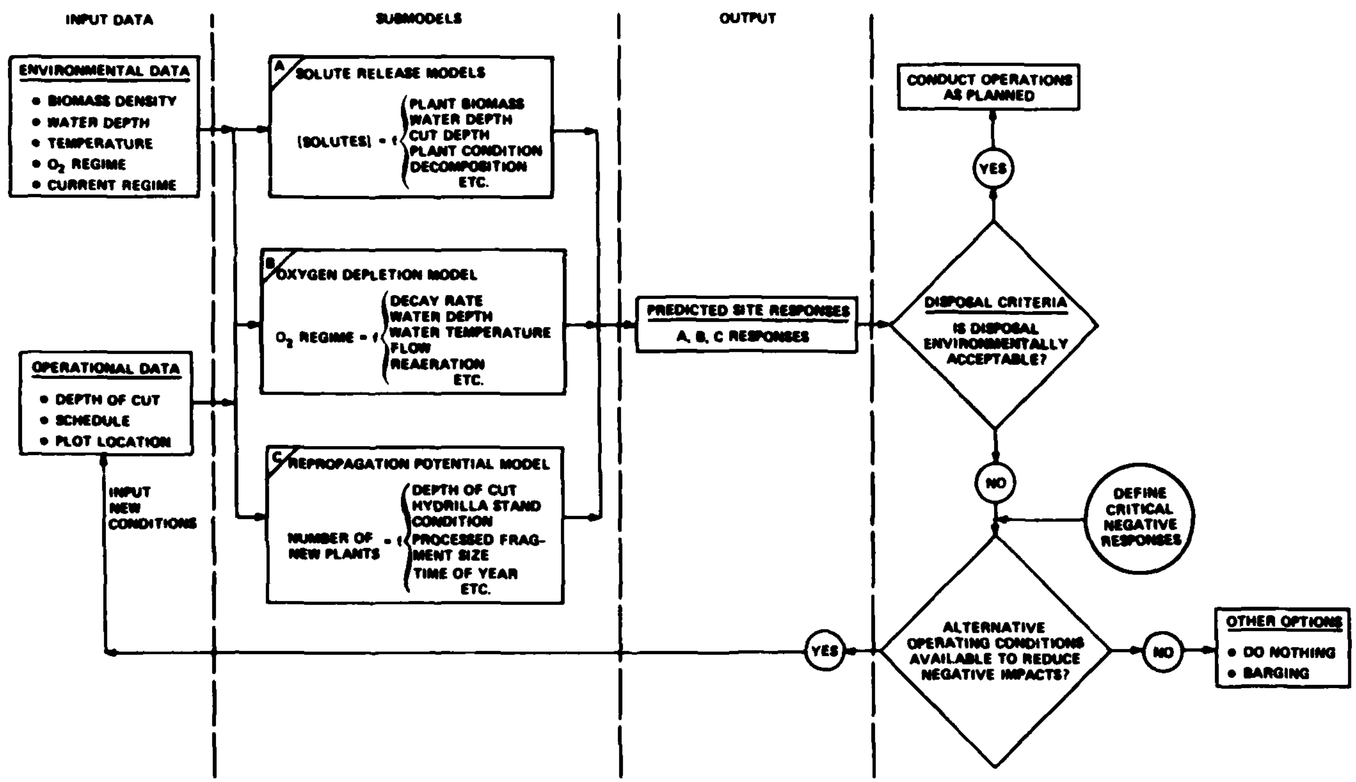

Figure 1. Aquatic disposal of processed hydrilla

in the predictive methodology and possibly identify additional environmental factors and relationships that need to be incorporated into that methodology.

Once the predictive methodology has been satisfactorily developed and validated and the resulting predictions for a particular site have been obtained, the predictions will be compared against certain environmental criteria. Here, a decision will be made as to environmental acceptability of the predicted site response. If it is considered acceptable, harvesting and disposal operations can be initiated; however, if it is not acceptable, a determination will be made as to whether acceptable changes in operating factors such as depth of cut (which controls mass of disposed material) or scheduling of operations could minimize unacceptable site responses.

The present approach is to build a simple, user-oriented model to predict the "worst case" response for aquatic disposal at a particular site. If worst case responses are considered environmentally acceptable, then aquatic disposal of processed plant material would be used, thereby resulting in a reduction of the overall cost of aquatic plant control for the water body. The WES first-generation predictive model will be developed during FY 81 and 82 and will be used to support the Jacksonville District operation program. Further development of the model will depend on future funding and time constraints.

Prediction of Aquatic Disposal Effects

Solute release

Mechanical processing of hydrilla causes disruption of plant tissue and leakage of internal and interstitial fluids, which results in immediate release of soluble organics and other solutes to the water column. Elutriate type tests using processed hydrilla were performed during FY 80 to obtain preliminary estimates of quantity and composition of solutes released to a water body from aquatic disposal of processed (chopped) hydrilla (Table 1). Additional slower release of mineralized solutes will occur during decomposition of the processed hydrilla. Estimates of composition and release rate of solutes will be obtained in controlled laboratory decomposition tests. These types of estimates will be used in the model to predict the amount of solutes released to the water body as a function of site and operational conditions.

Oxygen depletion

Decomposition of processed hydrilla will affect the disposal site by consuming dissolved oxygen in the water column. Laboratory decomposition rate studies are planned to estimate decomposition rate. It is anticipated that decomposition studies will reveal a two-step process, rapid decomposition of soluble labile organics followed by slower decomposition of more refractory particulates.

Once the decomposition rate(s) has been estimated, oxygen depletion over time will be predicted for the potential disposal site.

Repropagation potential

It was hypothesized that the processed hydrilla would regrow if it were allowed to drop directly back into the water from the hammermill. To check this, a single aquarium test was performed in FY 80. A 19-ℓ aquarium was filled with Withlacoochee River water. Four litres of organic muck was collected from an area of healthy hydrilla growing in the river. The sediment was passed through a sieve to remove hydrilla plant material, then placed in the aquarium. The aquarium was placed in a window shaded from direct sunlight by a sheet of thin white paper. Illumination level at the water surface was 10 percent of direct unshaded solar radiation (equivalent to 1 m depth in Withlacoochee River). Processed hydrilla was sampled from the harvesting operation in Orange Lake on 10 June 1980. At the time of sampling, a 0- to 4-ft layer of topped hydrilla was being harvested. Two hundred millilitres (180 g wet weight, approximately 9 g dry weight) of processed hydrilla was placed in the aquarium. Water temperature in the aquarium ranged between 22° and 30°C during the 5-week test. By the end of the test, all plant material except for five stem fragments had visibly decomposed. Of the five surviving pieces, three rootless floating stem segments were producing new growth and two segments rooted in bottom sediment were showing new growth. Converting this one test to unit weight, 1 kg wet weight of processed hydrilla would produce 28 new plants.

Recent literature* has identified the number of nodes on a hydrilla stem fragment as an important factor in fragment survival potential. Under controlled conditions, the survival potential for stem fragments with 1, 2, 3, 4, and 5 nodes was 28, 42, 80, 83, and 100 percent, respectively.

To determine stem size and nodal distribution of processed hydrilla, a sample was collected while the harvester worked a 0- to 0.6-m layer of topped-out hydrilla on the Withlacoochee River. A number of nodes and stem lengths on the sample were counted and measured (Figures 2 and 3). Median stem length was 6 mm; only 2.9 percent of total stem fragments were over 20 mm (750 pieces greater than 20 mm per kilogram wet weight). Nodal distribution varied with the portion of the plant harvested and the condition of the hydrilla stand (topped or not topped). Applying the measured nodal distribution to the literature survival estimates gave a repropagation potential estimate of 3585 plants per kilogram wet weight (Table 2). This estimate is over two orders of magnitude greater than that determined in the single aquarium test. Substantial differences exist between the stem segments tested by Langeland and Sutton and the plant material generated by the Limnos processor and tested in the aquarium. Laboratory survival tests by Langeland and Sutton used long

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* Langeland, K. A., and Sutton, D. L. 1980. "Regrowth of Hydrilla from Axillary Buds," Journal of Aquatic Plant Management, Vol 18, pp 27-29.

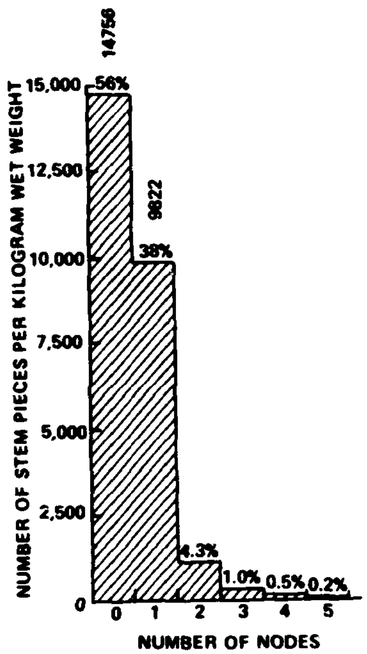

Figure 2. Nodal distribution of processed hydrilla

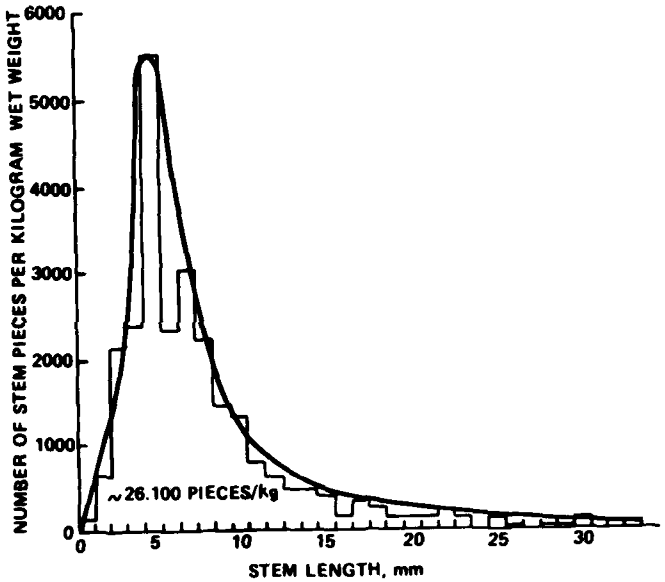

Figure 3. Stem length distribution of processed hydrilla

length fragments of subapical stems only, unlike the short fragments produced by the processor. This may make comparision between the two studies questionable, but it also suggests that stem length (or unit weight of fragments) may be another important survival factor.

It is anticipated that many additional factors influence repropagation potential: plant age, additional mechanical injury incurred in processing, temperature, nutrient levels, light, etc. Studies are planned to identify factors affecting fragment survival and to better quantify survival and regrowth potential. Once mechanical factors affecting survival have been identified, processor designs can be selected that will minimize or eliminate the repropagation potential of the processed hydrilla. An estimate of survival potential and factors influencing it will be used in the model to predict number of new plants possible as a result of aquatic disposal of processed hydrilla.

Preliminary Field Test

A preliminary field test was conducted during FY 80 to qualitatively observe full-scale disposal effects and determine duration and spatial extent of measurable water quality effects. The test is briefly described in the following paragraphs.

Princess Lake on the Withlacoochee River was selected for conducting large-scale tests (Figure 4). Two adjoining 250- by 1250-ft plots in topped-out hydrilla were established, one for use as a reference plot and the other for harvesting and disposal operations. Plant density in the 0- to 2-ft depth layer was determined by taking 15 systematically selected samples in each plot with an Allied Aquatics Sampler. The plot to be harvested (Plot A) had an average plant density of 8.5 tons (wet weight)/acre (range 0.8 to 12.6 tons/acre) and an average depth of 3.9 ft. The reference plot (Plot B) had an average density of 8.1 tons/acre (range 0 to 12.6 tons/acre) and an average depth of 2.5 ft. Both plots were established within buffer zones of topped-out hydrilla, and no flow (zero water velocity) was detectable in either plot. The lake bottom in both plots was blanketed by a thick layer of soft organic muck, much of which smelled of hydrogen sulfide indicating anaerobic conditions.

Cutting and harvesting began at 1000 hr and ended at 1545 hr on 7 July 1980. The cutter boat cut 18-ft-wide swaths along the long axis of the plot and the harvester followed collecting the floating hydrilla. The collected plants were passed through the hammermill, then dumped immediately back into the water.

Water quality sampling stations were located upstream and downstream of Princess Lake as well as within and around Plots A and B. Sampling was performed 24 hr and 1 hr prior to commencement of harvesting and 1, 18, 44, and 90 hr after the end of harvesting and disposal. All sample times, except the one immediately after harvesting, were in early morning hours at the anticipated time of diurnal oxygen minimum. In situ water quality probe measurements (temperature, dissolved oxygen, pH,

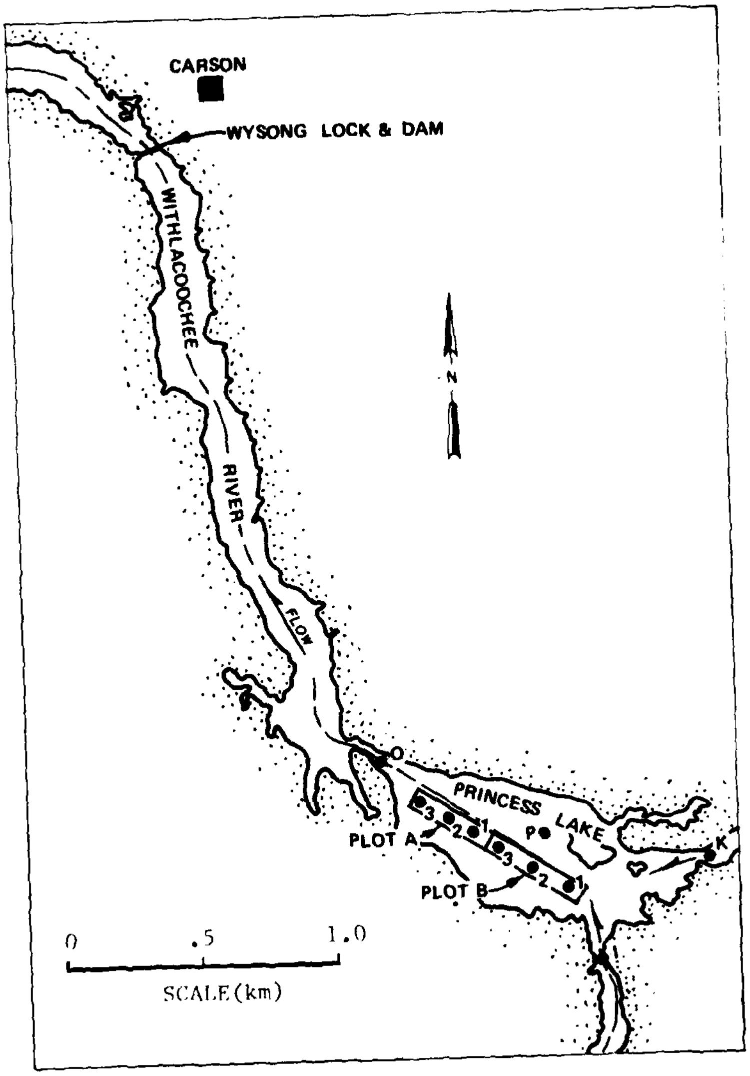

Figure 4. Withlacoochee River mechanical harvesting study site

conductivity, and oxidation-reduction potential) were taken at the top, middle, and bottom of the water column. Samples for biological oxygen demand, suspended solids, and turbidity were taken at middepth only.

The most immediate and apparent effect of harvesting was that the extreme temperature and oxygen stratification occurring in the surface layer of the water column in topped-out hydrilla stands was eliminated. These areas then became uniformly low oxygenated and homothermal, as was characteristic of uninfested areas of the lake. A surface plume of "green water" was observed behind the harvester for a short distance. Dense leaf material sank immediately while stem pieces floated and were observed still floating 4 days later. Three days after harvesting, substantial amounts of brown leaf material were observed at the surface floating by attached bubbles, probably indicating intense decomposition. No water quality effects were observed downstream of the site (in relation to upstream) after disposal. This may have been due in part to the plots being surrounded by topped-out hydrilla stands. No elevated biological oxygen demand values or depressed bottom oxygen levels were observed in the test plot (in relation to the reference plot or upstream stations) after harvesting and disposal. No elevated turbidity or suspended solids levels were observed in the test plot at the first sampling time (1 to 7 hr after the harvester passed over those points).

Lack of detectable effects from processed hydrilla disposal was surprising. The occurrence of visible effects (turbidity and suspended solids) was a much shorter lived phenomenon than could be detected by the sampling design performed. Oxygen uptake from disposed processed plant material decomposition did not detectably depress dissolved oxygen levels at the disposal site, possibly indicating that decomposition was sufficiently slow such that the slow natural reaeration of standing water was adequate to replenish any oxygen depletion, or that the oxygen demand of the processed hydrilla was relatively small compared with the existing oxygen demand of the organic muck bottom. Use of a "buffer zone" of topped-out hydrilla may be a useful technique to localize effects of disposal. Results of the test will be useful in designing future sampling programs to detect subtle and short-term effects.

Work Planned for FY 81

Additional large-scale tests will be conducted during FY 81 to provide validation data for the water disposal model. Elutriate type tests will be conducted to estimate immediate release of solutes as a function of plant fragmentation size and plant condition. Decomposition tests will be conducted to estimate decay rate constants and mineralization as a function of temperature and plant condition. Processed hydrilla regeneration tests will be performed to quantify survival rate and identify factors affecting survival rate. Automated in situ water quality field stations will be used to collect continuous data on important parameters.

Table 1

RELEASE OF DISSOLVED SUBSTANCES FROM PROCESSED HYDRILLA SAMPLES OBTAINED FROM ORANGE LAKE, AUG 1980

	(A) PROCESSED HYDRILLA % ON DRY WT BASIS	(B) DISSOLVED SUBSTANCES IN RECEIVING WATER	(C) DISSOLVED SUBSTANCES IN 10% PROCESSED HYDRILLA SLURRY	(C) - (B) = (D) RELEASED FROM PROCESSED HYDRILLA	(D) X 10 = (E) SOLUTE RELEASE PER WET WT OF PROCESSED HYDRILLA, MG/KG	(F) PROCESSED HYDRILLA WET WT COMPOSITION MG/KG	(E/F) IMMEDIATELY AVAILABLE, %
SOLIDS, 105°C	6.9	68 MG/ℓ	507 MG/ℓ	439 MG/ℓ	4390	69,000	6.4
VOLATILE SOLIDS 475°C	85	22.4 MG/ℓ	208 MG/ℓ	186 MG/ℓ	1860	58,600	3.2
FIXED SOLIDS	15	45.6 MG/ℓ	299 MG/ℓ	253 MG/ℓ	2530	10,400	24
CONDUCTIVITY μMHOS/CM		60	520	460			
ALKALINITY AS $CACO_3$		31 MG/ℓ	57 MG/ℓ	26 MG/ℓ	260		
BOD_5 DAY			140 MG/ℓ (CORRECTED)	140 MG/ℓ	1400		
ORTHO-PO_4 AS P		<0.010 MG/ℓ	4.75 MG/ℓ	4.74 MG/ℓ	47.4		
TKN, AS N	2.54	0.76 MG/ℓ	12.3 MG/ℓ	11.5 MG/ℓ	115	1,750	6.6
TOTAL PHOSPHORUS AS P	0.32	<0.10 MG/ℓ	5.62 MG/ℓ	5.52 MG/ℓ	55.2	220	25
NO_2 + NO_3 AS N		0.011 MG/ℓ	0.153 MG/ℓ	0.142 MG/ℓ	1.42		
CA	1.71	7.58 MG/ℓ	6.87 MG/ℓ	0	0		0
FE	0.44	<0.05 MG/ℓ	0.482 MG/ℓ	0.432 MG/ℓ	4.32	306	1.4
MG	0.55	1.88 MG/ℓ	7.25 MG/ℓ	5.37 MG/ℓ	53.7	377	14
K	1.12	0.157 MG/ℓ	37.1 MG/ℓ	36.9 MG/ℓ	369	770	48
NA	1.95	4.88 MG/ℓ	69.0 MG/ℓ	64.1 MG/ℓ	641	1,343	48

Table 2

PROCESSED HYDRILLA REGENERATION POTENTIAL, BASED ON NODAL DISTRIBUTION AND LABORATORY SURVIVAL TEST *

NO. OF NODES/ STEM SEGMENT	NO. OF SEGMENTS IN 22.5 G SAMPLE	PERCENT OF TOTAL SAMPLES	ESTIMATED NO. OF SEGMENTS IN A 1-KG SAMPLE	SURVIVAL POTENTIAL %	ESTIMATED NO. OF PROPAGULES PER KG OF CHOPPED PLANT MATERIAL
0	332	56.00	14,756	0	0
1	221	38.00	9,822	28	2,750
2	25	4.30	1,111	42	467
3	6	1.00	267	80	214
4	3	0.53	133	83	110
5	1	0.17	44	100	44
TOTAL	588	100.00	26,133		3,585

*Langland and Sutton (1980).

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

Prediction of Hydrilla Growth and Biomass for Mechanical Harvesting Operations

by

Andrew Miller*

Introduction

Research on the use of mechanical harvesting systems to control extensive infestations of aquatic macrophytes in lakes and rivers of interest to the Corps of Engineers is presently being conducted by WES. The objective of these studies is to develop efficient, cost-effective procedures that can be utilized in a variety of water bodies where differing ecological conditions prevail. This particular study is limited to the prediction of growth and biomass of the aquatic submersed macrophyte *Hydrilla verticillata* Royle. Since its introduction in Florida in the early 1960's, hydrilla has spread quickly and choked many shallow lakes and streams. Its rapid colonization rates when introduced are the result of high photosynthetic rates and efficient vegetative reproduction (Haller and Sutton 1975).

Harvesting aquatic macrophytes mechanically is a four-step process consisting of the cutting at a select depth, the removal of the plants from the water, the mechanical processing of the plants, and the disposal of the plants. Precise information on the operating times and efficiencies of the equipment, in addition to data on water depth, distance to disposal site, and biomass of plants, are necessary to design an organized and cost-effective mechanical harvesting operational program.

The mechanical harvesting of aquatic plants is a process well suited to simulation and analysis with computer models. By simulating the harvesting procedure, it is possible to analyze all aspects of the operation to determine the most effective use of the equipment during field deployment. Currently, there are three mathematical models available that simulate the operation of equipment while harvesting aquatic plants. The first, a simulation model developed for the Aqua Trio harvesting system entitled SHAP, is a stochastic model utilizing random-time sequential events. This model has recently been modified by Perrier and Gibson (1980). The second model, the Limnos Model (Limnos Ltd. 1979), is a discrete time deterministic model originally written for use with a programmable calculator. Both models were designed to provide information

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

needed to plan and conduct a program for harvesting aquatic macrophytes. The third model, recently developed by Hutto (1980), is a first-generation model (HARVEST) currently being used to obtain predictions for the Limnos harvesting system in Orange and Bonnet Lakes, Florida. The HARVEST model, while based in part on the other two models, essentially represents a more deterministic approach to the overall mechanical harvesting operation. The WES HARVEST model requires as input the plant biomass values at specific depths in the water column, the areal distribution of aquatic macrophytes in a lake or river, and water depth and water velocity.

The purpose of the research discussed herein is to develop a method for predicting the growth and weight (or biomass) of hydrilla, based upon biological and ecological attributes of the species. This simulation model will consider conditions of water depth and existing community structure where equipment harvesting operations studies are to be conducted. The model will predict for discrete water depths and specific areas within each 2-ft grid cell of surface area of the harvesting site.

Existing Methods and Models for Simulating Plant Growth and Biomass

Schramm (1979) compiled existing information and developed a model that predicted growth rates and biomass of hydrilla based on water temperature, length of photoperiod, and season. In addition, the model included growth and cropping (feeding) rates of the white amur (*Ctenopharyngodon idella* Val), an herbivorous fish that has been introduced into lakes for the control of hydrilla and other submersed macrophytes.

The portion of Schramm's model that simulated hydrilla growth (Figure 1) utilized as input parameters initial plant biomass and the carrying capacity of the lake for hydrilla. The relationship of temperature and photoperiod to growth of hydrilla was based upon previous studies. The model calculates a new value for plant biomass (PB) for each month based upon PB calculated for the most recent time interval. Stated simply, the biomass of each month is the previous month's biomass multiplied by a factor derived by the product of a photoperiod coefficient by the sum of a temperature and the month's coefficient. Figure 2 depicts a 12-month iteration of the model, beginning in January with 100 kg of plant material within a lake. This prediction (Figure 2) did not consider the "cropping effects" of the white amur on the hydrilla and assumed that the carrying capacity of the lake for hydrilla was not achieved during the 12-month period.

This simulation does not provide for the biomass data as currently needed in the HARVEST model under development at WES. Schramm's model does not consider growth of plants in a specific depth layer of water for specific portions of a plot or lake. The iteration period, 1 month, is also considered too long for realistic growth rates of plants as measured by WES in Orange and Bonnet Lakes during the summer of 1980.

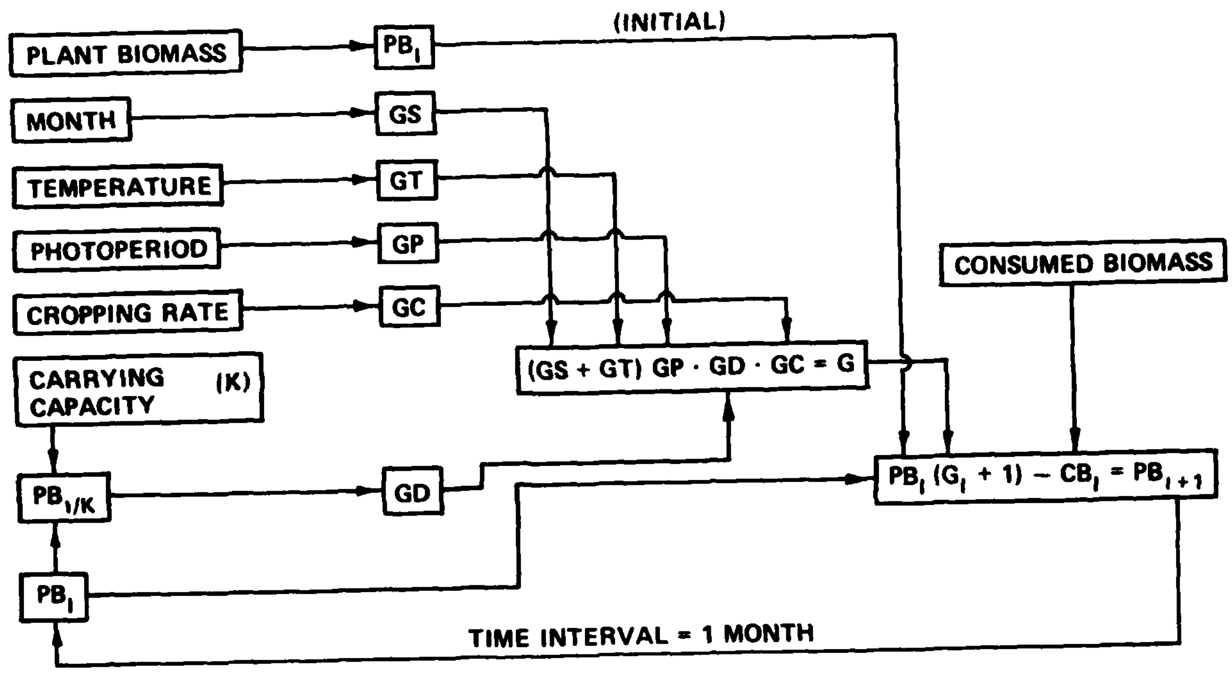

Figure 1. Hydrilla portion of the white amur stocking rate model (after Schramm (1979))

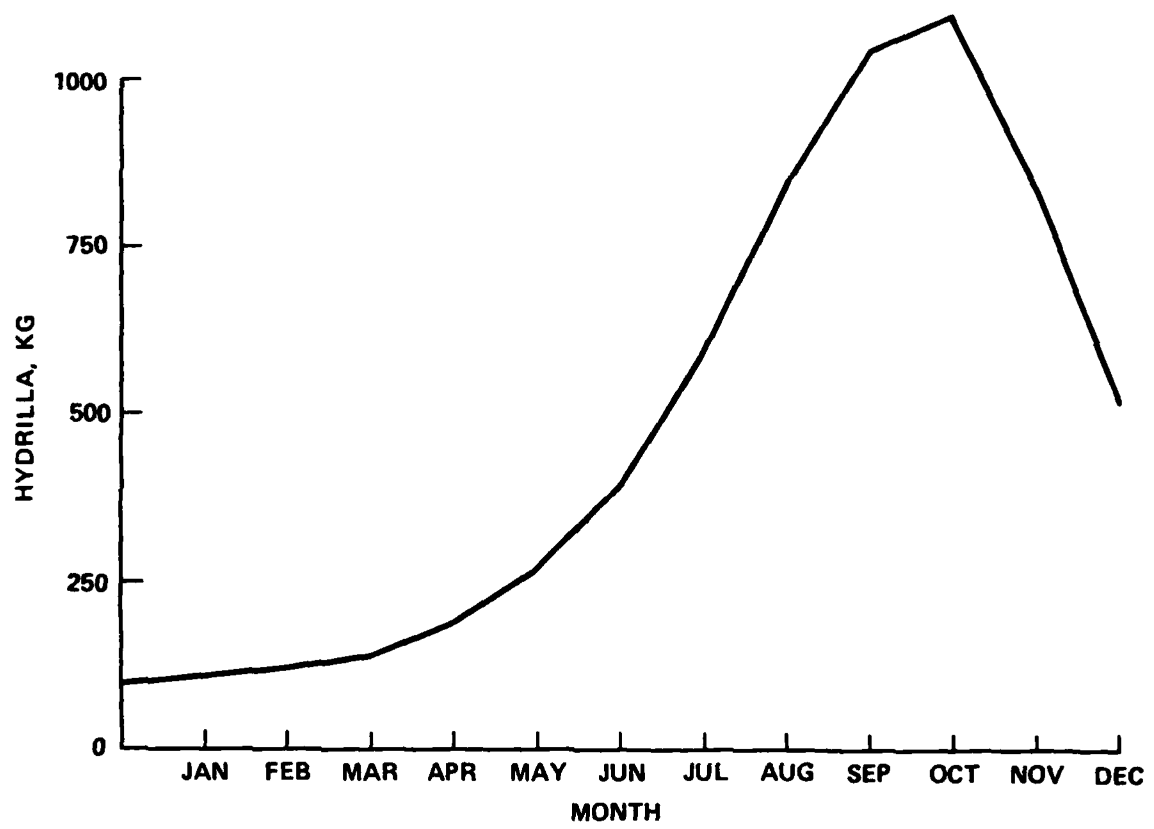

Figure 2. Prediction of hydrilla biomass for a 12-month iteration using the Schramm model

Ewel and Fontaine (1979) developed a model to predict biomass accumulation from aquatic macrophyte growth in Lake Conway, Florida. Their model considers tuber formation and sprouting of tubers as well as the cropping effects of fish and epiphytic algae. The final equation (Figure 3) includes variables such as light availability and consumption of hydrilla plant material by invertebrates and herbivorous and young primary fish. The Ewel and Fontaine (1979) model, while broad in scope, is also still a general approach that does not consider biomass accumulation at specific depths and areal distributions of aquatic macrophytes. There is a need for a methodology specific enough to allow prediction to be obtained for discrete depths and subunits in a large plot, yet general enough in its input requirements so that it can be applicable to water bodies with varying temperature, water and sediment quality and nutrients, and light intensity conditions.

The WES First-Generation Hydrilla Growth and Biomass Model (GROBIO)

The first-generation hydrilla growth and biomass model (GROBIO) will provide estimates of growth and biomass at specific water depths (D) and at specific times (T). Depths will be for 1-ft intervals to conform with requirements of the WES HARVEST model. Using this methodology, it will be possible to predict rates of growth and accumulated biomass for the 0- to 1-ft water layer, 1- to 2-ft layer, or any portion of the water column. The smallest unit of surface area of the lake will be one grid cell or 4 sq ft. Plant growth will be considered homogeneous for a specified grid cell of the plot. If the plants or their growth rates are not homogeneous throughout the lake, then the lake will be subdivided according to the areal distribution of the plants. In this manner, various plant distributions and different plant growth rates can be considered. Predictions will be provided for several 1-day growth periods. Growth rates, biomass accumulation, water temperature, and levels of incident radiation will be unchanged during this time period. Initially, GROBIO will be designed to provide predictions for up to 365 days (i.e. 1 year). By using information on plant senescence, periods greater than 1 year can be predicted. However, for the first-generation model, the impacts of plant senescence on growth and biomass will not be considered.

The primary forcing functions needed for GROBIO are ones for elongation (EL) and branching (BR) of the hydrilla shoots. This model will not determine biomass directly, but will calculate growth and branching increments for each depth layer of water during the 1-day period. The total increase in stem lengths at each depth will be calculated and then converted to biomass.

The EL and BR of hydrilla are considered to be directly related to two parameters, water temperature and incident solar radiation. For this first-generation simulation, the results of Barko et al. (1980)

BIOMASS OF AQUATIC MACROPHYTES AND ASSOCIATED EPIPHYTIC ALGAE

MACROPHYTE BIOMASS = [(AVAILABILITY OF LIGHT X PHOTOSYNTHETIC RATE AT AVAILABLE LIGHT LEVEL X MACROPHYTE BIOMASS X EFFECT OF TEMPERATURE ON PHOTOSYNTHESIS X CONVERSION FROM KILOCALORIES TO CARBON FOR PHOTOSYNTHESIS X ORTHOPHOSPHATE IN THE EPILIMNION) + *(TUBER GERMINATION IN SPRING)* – (RESPIRATION RATE) – (SLOUGHING RATE OF LEAVES) – (TUBER FORMATION IN FALL) – (CONSUMPTION BY BENTHIC INVERTEBRATES X CONSUMPTION BY HERBIVOROUS FISH X CONSUMPTION BY YOUNG PRIMARY PREDATOR FISH)]

Figure 3. Equation for biomass of aquatic macrophytes and associated epiphytic algae (after Ewel and Fontaine (1979))

will be used to provide estimates of the effects of these variables. In their studies, total increase in hydrilla shoot length was measured over a 6-week period at five different temperatures (Figure 4). Additionally, the number of new shoots per stem was also noted under these same conditions. The relationship between shoot length and water temperature was linear ($r = 0.99$); the relationship between water temperature and number of new shoots produced was hyperbolic ($r = 0.64$). In a second laboratory experiment, the relationship between varying light levels (from 0 to 93 percent shade) and increase in shoot length and shoot number (Figure 5) was determined for hydrilla. The relationship between incident radiation and shoot production and shoot elongation is inverse; at decreased radiation levels there is more shoot elongation and fewer shoots are produced. For these experiments, incident radiation was measured in microeinsteins per square metre per second, a measure of the amount of photosynetically usable light that reaches the plant in the water column.

Taken together these two parameters impact branching and elongation of the plant values for a 1-day period in the following manner:

$$BR = (0.11 \times \text{water temp}) + (0.14 \times \text{percent shade}) - 1.3 \tag{1}$$

$$EL = (1.22 \times \text{water temp}) + (0.09 \times \text{percent shade}) - 17.9 \tag{2}$$

Haller and Sutton (1975) established a relationship between water depth and percentage of incident solar radiation. Figure 6 presents their data for radiation penetration through open water and through a mature hydrilla canopy. Using the relationship between water depth and percent incident radiation, it is possible to relate depth to amount of incident radiation. Equations 1 and 2 above now become:

$$BR = (0.11 \times \text{water temp}) + (0.22 \times \text{depth (cm)}) - 1.3 \tag{3}$$

$$EL = (1.22 \times \text{water temp (°C)}) + (0.14 \times \text{depth (cm)}) - 17.9 \tag{4}$$

The elongation value is total length in centimetres and branching rate is in terms of total branches produced, which includes all lateral branches and all shoots originating below the water surface.

This relationship does not include the effects of hydrostatic pressure, which become significant for many species at about 30 ft (Wetzel 1975). Because most of the water bodies to be considered will have depths less than 15 to 20 ft, the effects of hydrostatic pressure will not be considered. The procedure for determining total shoot lengths for each layer of water for the 1-day interval ($i + 1$) will be

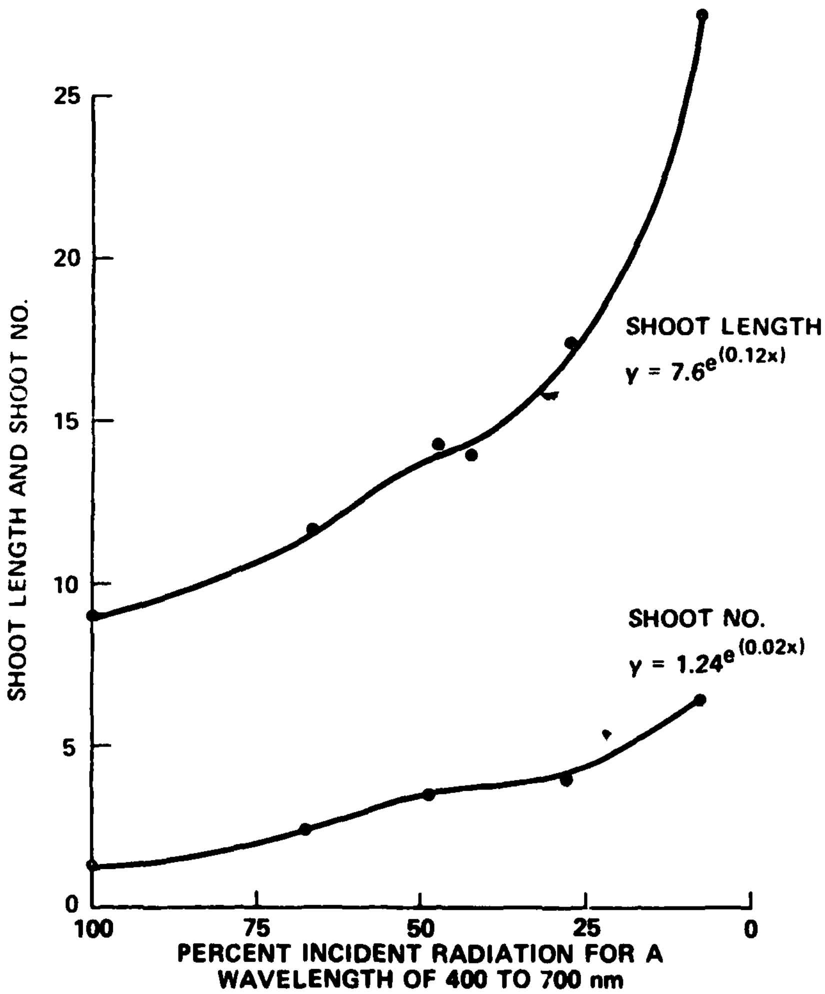

Figure 4. Hydrilla shoot length and shoot number at five different incident radiation levels (from data supplied by Barko et al. (1980))

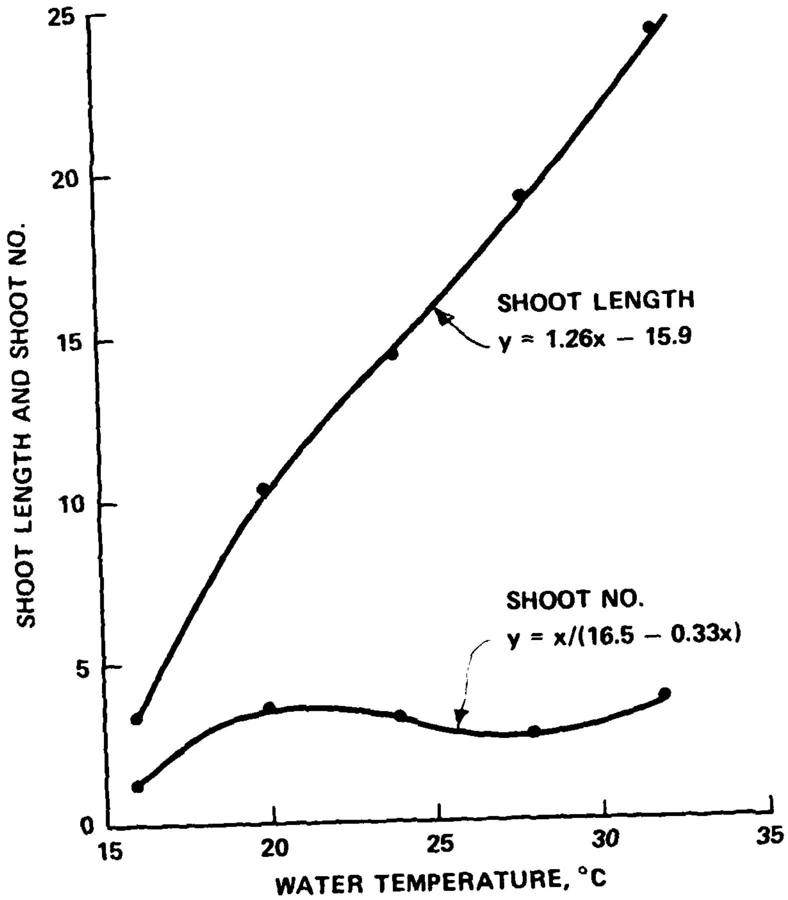

Figure 5. Hydrilla shoot length and shoot number at five different water temperature values (from data supplied by Barko et al. (1980))

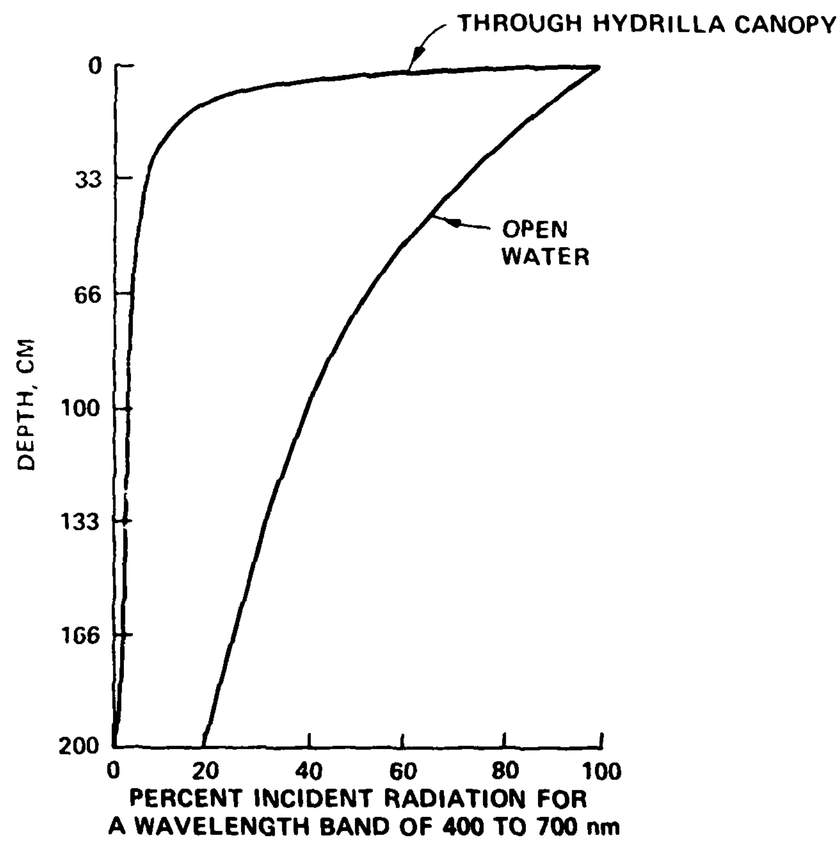

Figure 6. A comparison of depth (cm) and percent incident radiation (nm) for open water conditions (no plants) and through a hydrilla canopy (from Haller and Sutton (1975))

conducted as follows for each water depth D and time T :

$$\text{Len.}\,{}^{(D,T)}_{(i+1)} = \left[\text{No. stems}^{(D,T)} \times \text{Ave len}^{(D,T)}\right] + \left[EL^{(D,T)} \times \text{No. stems}^{(D,T)}\right] + \left[\text{No. stems}^{(D,T)} \times BR^{(D,T)} \times (EL^{(D,T)}/2)\right] \quad (5)$$

Branching and elongation values will be calculated for each time interval based upon incident solar radiation and water temperature. Total shoot length for each depth layer of water will be the sum of the previous total shoot length and the amount of growth from elongation of these shoots. Additionally, the number of new branches will be calculated for each layer of water. Elongation values for a period of 1 day will be considered equal to EL/2, which assumes that 50 percent of the branches sprout (on the average) at midday.

The relationship between average weight of plant stems at specified depths in the water column has been determined experimentally for plants collected in Orange Lake, Florida (Figure 7). Portions of the stem close to the surface were heavier than a similar portion of the plant near the bottom of the water column. This was principally the result of differing internodal distances. Leaves were up to 4 in. apart near the bottom of the plant and overlapping the next leaf by as much as 50 percent at or near the water surface.

Considering the entire plant, hydrilla collected from Orange Lake was about 10 times heavier than individuals collected from Bonnet Lake on the Withlacoochee River (Figure 8). Whether this was the result of previous harvesting schedule, nutrient differences between sediments, water temperatures, or other factors, has not been determined. However, from 30 to 60 percent of the biomass of hydrilla is within the upper 2 ft of the water surface in plants collected from both lakes.

The impact of mechanical cutting on regrowth rates was studied by WES for hydrilla in the Withlacoochee River and Orange Lake in Florida in the summer of 1980. In the river, plants were cut 2 to 3 ft below the water surface and then monitored for regrowth. Five to six weeks was required for the plants to reach the water surface during July and August 1980. The effects of factors such as time of the year, depth, and frequency of cuts on EL and BR are not completely understood. While the preliminary WES field studies concerning plant regrowth have provided some data, the precise relationship between cutting schedule and EL and BR can best be understood and quantified using controlled laboratory experiments supplemented by field experiments.

For the WES GROBIO model, carrying capacity will be based upon maximum values that have been calculated using measured weight sample data collected in the lakes under study in Florida.

Although g[illegible]atly reduced when compared with terrestrial plants, the roots of aquatic plants function in the uptake of nutrients. Barko

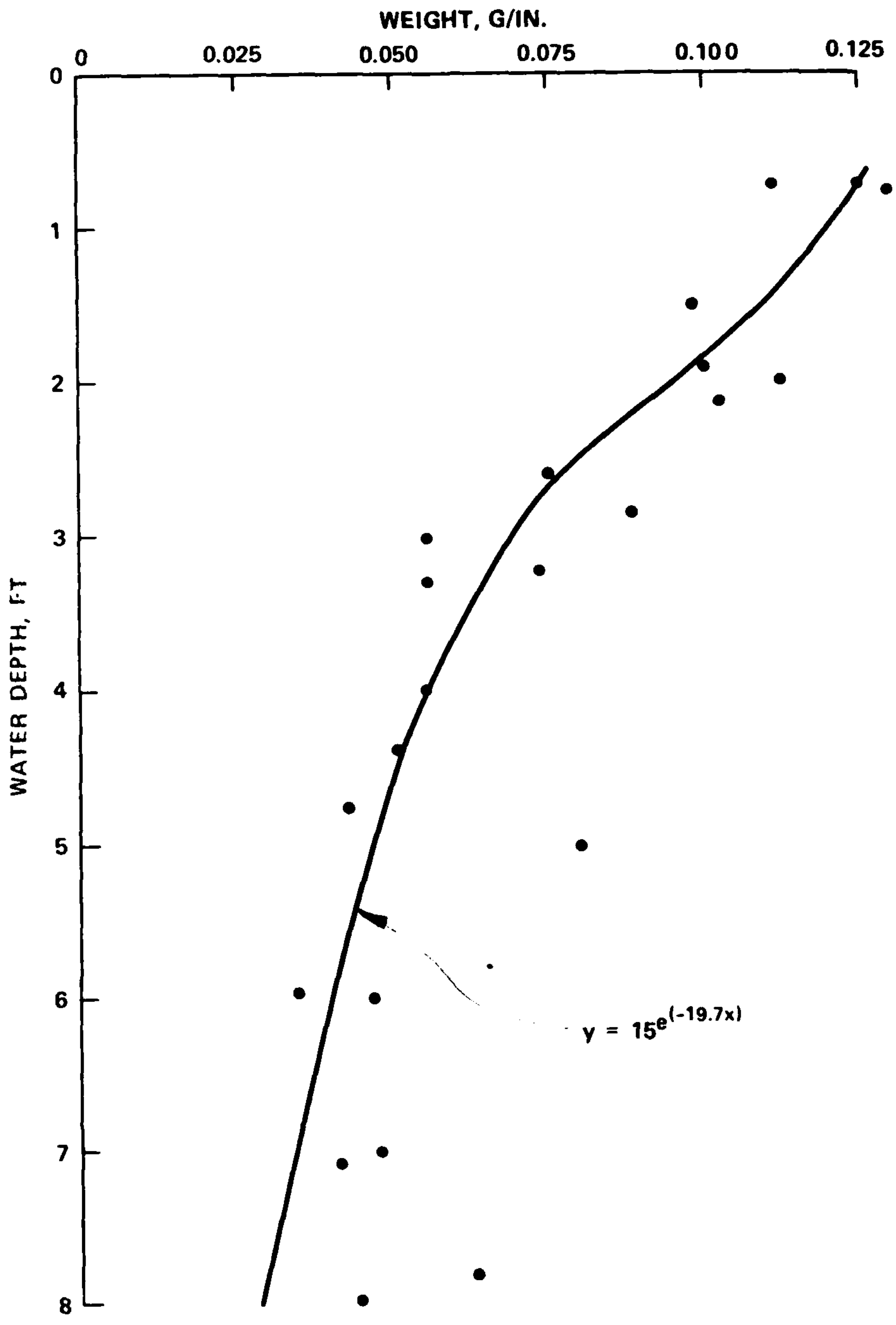

Figure 7. Relationship between average weight of plant stems and differing water depths, Orange Lake, Florida, August 1980

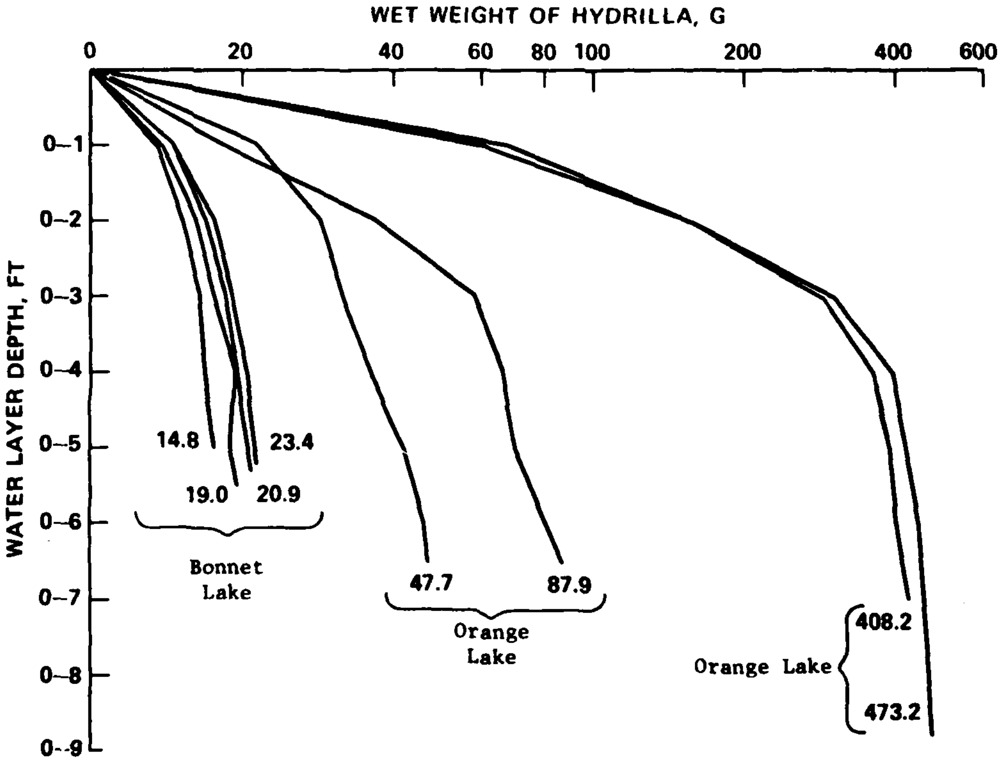

Figure 8. Wet weight of hydrilla by layer depth, Orange and Bonnet Lakes, Florida, August 1980

and Smart (1980) have demonstrated the mobilization of sediment phosphorus into the roots of hydrilla and subsequent translocation into shoot tissue. Preliminary biomass studies in Florida have identified variations in weight distribution of plants in most lakes to be harvested. Additional work is needed to determine the effect of substrate composition on growth rates and stem density of hydrilla before their factors can realistically be incorporated into GROBIO.

The steps required for predicting plant growth and biomass of hydrilla are outlined in Figure 9. Data that are needed for the model on water temperatures and solar radiation are being measured hourly by three instrumented field stations that have been established on the Withlacoochee River and Orange Lake and the data are being transferred to WES hourly using a GOES satellite transmission link. Water depth, stem density, and plant height for a designated time period are also input parameters for the lake to be harvested. For each 1-day iteration of the simulation, EL and BR will be determined; then these factors will be used to calculate total stem length for each water layer. Total biomass for each water layer will be determined from empirical information on the relationship between stem weights and stem lengths. The EL and BR will be recalculated as necessary for each 1-day period. When biomass has been calculated for a subplot within the lake, a second subplot can be analyzed. Ultimately, this methodology will provide biomass information for various water layers in the lake or portion of the lake. Verification of the prediction results for Orange Lake and the Withlacoochee River will be conducted primarily using measured biomass data collected from Bonnet Lake, Orange Lake, and the Withlacoochee River.

Conclusions

A first-generation model (GROBIO) to simulate plant growth and biomass accumulation by the aquatic macrophyte hydrilla is under development. The simulation is designed to predict plant elongation and branching values which are then converted to biomass. Empirical growth data on hydrilla for Orange Lake and the Withlacoochee River, Florida, and previous laboratory studies on hydrilla will be used for model check-out purposes. Verification of the model will be accomplished by evaluation of existing measured data and results of field experiments under way and planned for the summer of 1981.

When completed, GROBIO will yield growth and biomass values at specific times and depths in the water column for use as input to the WES HARVEST model. Analytical models that describe hydrilla growth and the mechanical harvesting process are needed to effectively plan and conduct aquatic macrophyte harvesting operations throughout the summer growth period. The first-generation growth and biomass model will not include the relationships between scenescence, sediment nutrient composition, and cutting schedules on hydrilla growth rates. However, these effects will be included in the second-generation model, which is planned for FY 82.

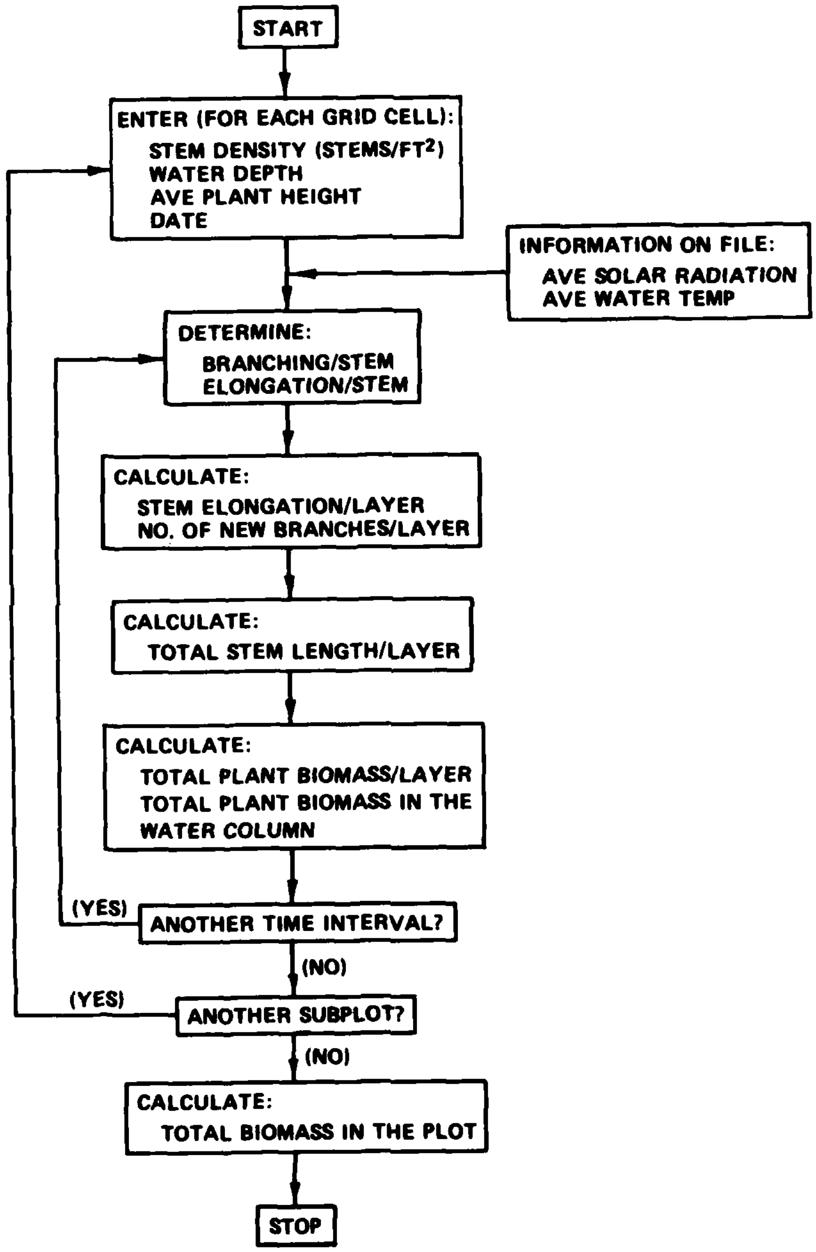

Figure 9. Flowchart of the first-generation plant growth and biomass model (GROBIO)

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CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by

Howard E. Westerdahl*

During the past fiscal year, considerable effort was directed at defining the testing conditions required to adequately evaluate new controlled-release herbicide formulations under laboratory and field conditions. Moreover, research was continued to improve and manufacture sufficient quantities of a controlled-release 2,4-D formulation for field evaluation and to identify naturally occurring chemical inhibitors for hydrilla control.

A working group representing the Water and Power Resources Service, U. S. Department of Agriculture (USDA), Corps of Engineers, and selected researchers from universities met during November 1979 to develop a standard laboratory plan for evaluating controlled-release herbicides to facilitate interlaboratory comparisons of test results. In the following papers, Dr. Kerry Steward of the USDA Aquatic Plant Management Laboratory in Fort Lauderdale, Florida, will discuss this plan and will present preliminary test results.

Mr. Ron Hoeppel, U. S. Army Engineer Waterways Experiment Station (WES), will discuss ongoing in-house research to determine the threshold herbicide levels required to control regrowth of nuisance aquatic plants. In addition, Mr. Hoeppel will discuss current FY 81 field evaluation plans for two selected controlled-release 2,4-D formulations provided under contract by Wright State University, and another formulation submitted by Westvaco, Inc. Dr. Frank Harris, Wright State University, will describe research results using chemical polymers as controlled-release carriers for 2,4-D. Dr. Chet Himel, University of Georgia, will discuss several patented controlled-release carrier systems currently being evaluated for use with aquatic herbicides. Finally, Dr. Dean Martin, University of South Florida, will summarize his efforts under contract with WES to extract, isolate, and identify a naturally occurring chemical inhibitor for hydrilla.

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CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Development of Controlled-Release Herbicide Technology Using Polymers

by

Frank W. Harris* and Mickey W. Whitlock*

Introduction

In an attempt to prepare a controlled-release herbicide system, the 2-acryloyloxyethyl ester of 2,4-dichlorophenoxyacetic acid (AOE 2,4-D) has been copolymerized with 2-hydroxyethyl methacrylate (HEMA). The resulting copolymers slowly undergo hydrolysis when immersed in water, thereby releasing 2,4-D. The rate of hydrolysis of a particular copolymer depends on the percentage of HEMA present in the initial monomer feed. An increase in the amount of HEMA present results in a faster release rate. In fact, copolymers prepared with monomer feeds containing less than 40 mole percent HEMA hydrolyze at almost imperceptile rates (Thompson 1978).

The compositions of the AOE 2,4-D/HEMA copolymers are nonuniform because the HEMA is considerably more reactive in the copolymerization. Hence, copolymer formed early in the reaction is rich in HEMA, while copolymer formed later contains considerably less HEMA. It was postulated that less HEMA would be needed to prepare copolymers with reasonable release rates if this monomer could be more uniformly distributed along the copolymer backbone. Thus, the major objective of this research was to synthesize copolymers of AOE 2,4-D and HEMA with uniform compositions and to compare their hydrolysis rates with those of analogous copolymers with nonuniform compositions. The procedure chosen to prepare these polymers involved the programmed addition of the comonomers throughout the polymerization.

A second objective of this research was to further study the copolymerization of another herbicidal monomer, i.e., 2-methacryloyloxyethyl 2,4-dichlorophenoxyacetate (MOE 2,4-D) with hydrophilic comonomers. In particular, MOE 2,4-D was to be copolymerized with glyceryl methacrylate (GMA) and 2,3-epoxypropylmethacrylate (EPMA). Several of these polymerizations were also designed to involve programmed additions of the comonomers throughout the polymerizations. Hydrolysis rates of all the copolymers were to be determined in reconstituted hard water.

The third objective of this research was to develop experimental procedures for the preparation of large quantities of the most promising

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copolymer systems, since relatively large amounts of the copolymers are needed for expanded field testing.

Results and Discussion

Monomers

AOE 2,4-D and MOE 2,4-D were prepared by the reaction of 2,4-dichlorophenoxyacetyl chloride with 2-hydroxyethylacrylate and HEMA, respectively (Post 1974). Both reactions were carried out in the presence of 3,5-lutidine, which was used to neutralize the liberated hydrochloric acid. GMA was prepared by the acid hydrolysis of EPMA (Refojo 1944).

Preparation of AOE 2,4-D/HEMA copolymers with uniform composition

The molar ratios of AOE 2,4-D and HEMA needed to prepare uniform composition copolymers containing 2:1, 1:1, and 1:2 ratios of AOE 2,4-D to HEMA were calculated by using the previously reported (Thompson 1978) values of 0.44 for r_1 and 2.62 for r_2. Due to the change in monomer composition that occurs as the copolymerization proceeds, the initial feed ratios will only afford the desired copolymer composition if the polymerization is carried out to low conversion. Of course, if the rate of copolymerization is known, the initial monomer composition may be maintained by making appropriate monomer additions as the polymerization proceeds. Thus, the next step in this study was to determine the rate of the monomer conversion to copolymer. A series of copolymerizations of 10 g AOE 2,4-D and 1.67 g HEMA (71:29 mole ratio) in 50 ml of MEK at 70°C was carried out for various periods of time. The polymerizations gave an average conversion of 20 percent per hour (Figure 1). Thus, in this hour of polymerization, 10 percent of each comonomer will be used. This 10 percent must be replenished if the initial molar feed ratio is to be maintained.

Copolymerizations of AOE 2,4-D and HEMA were then carried out using initial molar feed ratios of 83:17, 71:29, and 56:44 (Table 1). The copolymerizations were run in MEK at 70°C with AIBN as the initiator. An appropriate amount of each monomer was added after 1 hr so as to restore the initial monomer ratios. The monomer additions were repeated every hour for the next 2 hr. After the last addition, the reaction mixture was heated one additional hour, allowed to cool, and then added dropwise to 1000 ml hexane to precipitate the product. The white polymers were extracted overnight with ethyl ether to remove any unreacted monomer or initiator residues and dried under reduced pressure. The yields ranged from 43 to 75 percent.

This procedure gave very good results. The initial molar feed ratios given above were calculated to give desired uniform copolymer compositions of 66:34, 50:50, and 34:66, respectively. As determined by chlorine analysis, actual copolymer compositions of 75:25, 55:45,

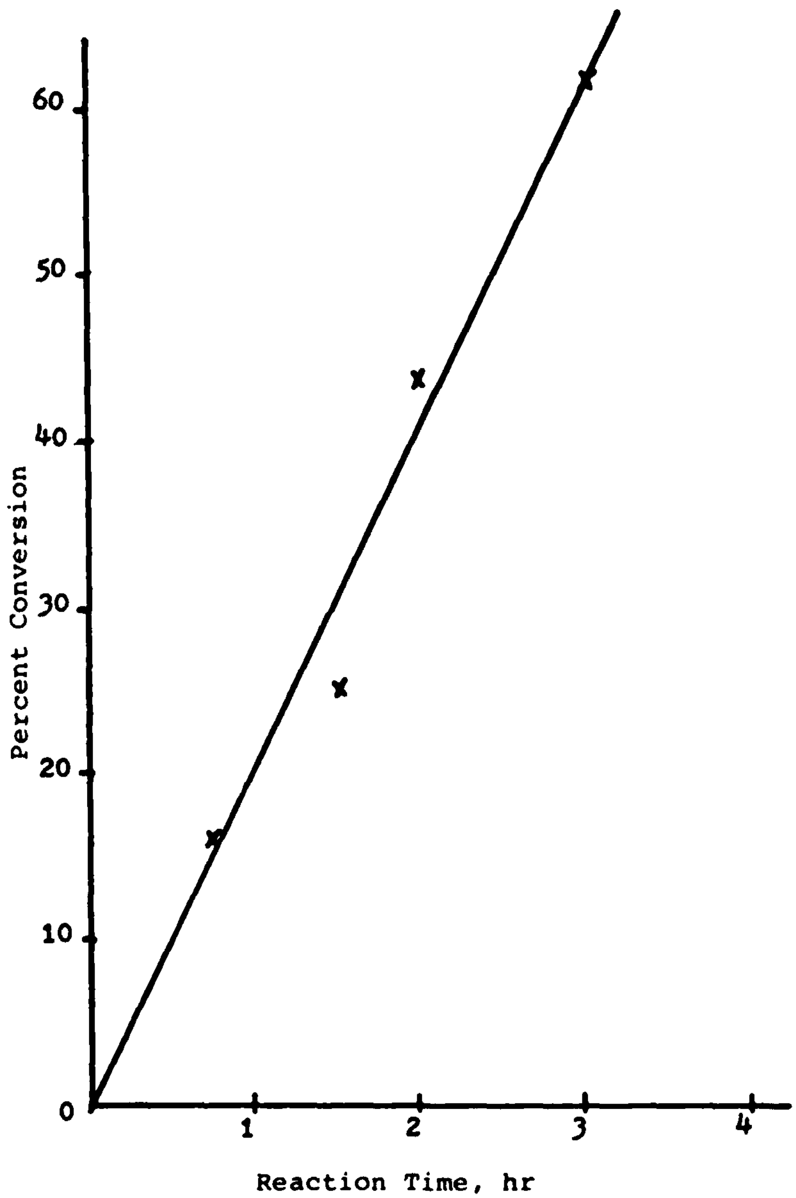

Figure 1. Conversion of AOE 2,4-D/HEMA copolymers

and 39:61, respectively, were obtained. In each case, the actual composition is slightly lower in HEMA content than the desired composition.

A slightly different procedure was also used to prepare copolymers with uniform compositions (Table 1). In this procedure only the more reactive monomer, i.e., HEMA, was added to the polymerization. Thus, 50:50, 60:40, and 70:30 molar feed ratios of AOE 2,4-D to HEMA were weighed out. In this case, however, only 25 percent of the HEMA was added to the initial polymerization mixtures. The remaining 75 percent was added in three equal portions at 1-hr intervals during the polymerization. After the polymerization had been allowed to proceed a total of 4 hr, the reaction mixture was worked up as described in the first procedure. The yields of the copolymers ranged from 42 to 57 percent.

This procedure also gave very good results. Here, actual copolymer compositions of 49:51, 58:42, and 65:35 were obtained. However, in this procedure the actual compositions were slightly higher in HEMA content than the desired. This procedure gave compositions closer to the desired than the first procedure.

The copolymers are soluble in several organic solvents such as THF, DMF, and aliphatic ketones, but are insoluble in aliphatic hydrocarbons, ethyl ether, and water. Their Tg's range from 14° to 25°C and increase as the percentage of HEMA in the copolymers increase.

MOE 2,4-D copolymers

As mentioned in the "Introduction," the second objective of this research was to further investigate the copolymerization of MOE 2,4-D and GMA. Since the reactivity ratios of these two monomers have not been determined, the initial molar feed ratios necessary to prepare copolymers with desired compositions could not be calculated. However, a short study was conducted to determine if the programmed addition of GMA to MOE 2,4-D would increase the hydrolysis rate of the resulting copolymer. Thus, two series of polymerizations were carried out (Table 2). In the first, molar feed ratios of MOE 2,4-D to GMA of 50:50, 70:30, and 90:10 were copolymerized by the traditional batch technique (Arah 1979). These copolymerizations were then repeated using a programmed addition procedure. Only 25 percent of the GMA feed was added to the initial polymerization. The remaining 75 percent was added in three equal portions at 1-hr intervals. All the reaction mixtures were then worked up by the method described for the AOE 2,4-D/HEMA copolymers. The yields of the copolymers ranged from 22 to 65 percent.

Copolymers 3a-3c, made by the first procedure, gave copolymer compositions of 48:52, 71:29, and 95:5, respectively. This close agreement between the initial feed ratio and composition suggests that these two monomers have similar reactivity ratios. In fact, it is very possible that $r_1 = r_2 = 1$. Such copolymer systems are termed "ideal" copolymers with both comonomers showing the same preference for adding one of the monomers over the other. Thus, the two type of units, MOE 2,4-D and GMA, are arranged at random along the chain in relative amounts determined by the composition of the feed.

The second procedure also gave very close agreement between the desired and actual compositions. Here, compositions of 48:52, 73:27, and 86:14, respe- vely, were obtained. Thus, either procedure could be used to afforu . desired copolymer composition. In each case, the composition would be approximately equal to the initial molar feed ratio.

The MOE 2,4-D/GMA copolymers are soluble and insoluble in the same solvents and the AOE 2,4-D/HEMA copolymers. However, the Tg's of these copolymers are higher, ranging between 30° and 54°C.

Finally, the copolymerization of MOE 2,4-D with a new monomer, i.e., EPMA, was investigated. Since GMA is prepared from EPMA, the synthetic route to copolymers prepared from this monomer involves one less step. Thus, molar feed ratios of MOE 2,4-D to EPMA of 50:50 and 60:40 were copolymerized in MEK at 70°C. The resulting copolymers were obtained in 91 and 87 percent yields, respectively. The copolymers are soluble in THF, DMF, and aliphatic ketones, but insoluble in aliphatic hydrocarbons, ethyl ether, and water. The copolymers have Tg's of 33° and 52°C, which are similar to those of the MOE 2,4-D/GMA copolymers.

Hydrolysis studies

Three 0.5-g samples of each copolymer were immersed in reconstituted hard water with a hardness of 160 to 180 mg/ℓ and pH of 8.0. The solutions were stored at ambient temperature and slightly agitated. Their 2,4-D content was determined periodically by spectrophotometric analysis. The hydrolysis data of all the copolymers are summarized in Figures 2-5. The release rate profile of a copolymer 5 prepared from a 50:50 molar feed ratio of AOE 2,4-D and HEMA using a standard batch technique has also been included for comparison (actual composition 46:54).

As shown in the figures, all the AOE 2,4-D/HEMA copolymers did undergo hydrolysis. Although only a small percentage of the 2,4-D contained in the copolymers has been released, the effect of the programmed addition of the monomers on the resulting copolymers' release rates can already be seen by comparing the release rates of the copolymers made by the two different procedures to that of copolymer 5. For example, copolymer 1b, which contains only 7 percent more HEMA, is releasing 2,4-D approximately three times faster than 5. Copolymer 1a has a release rate slightly faster than 5, even though it contains 9 percent less HEMA. The most dramatic example of the effect of composition is found when comparing copolymer 1c with 5. Although the former contains over 50 percent less HEMA, it releases 2,4-D at approximately the same rate as 5. All of these comparisons strongly suggest that copolymers with uniform compositions will undergo hydrolysis at faster rates than analogous copolymers with nonuniform compositions.

This conclusion can be further substantiated by comparing the release rates of copolymers 2a-2c with that of 5. Copolymer 2a, with only 3 percent less HEMA, releases 2,4-D approximately two times faster. Although copolymer 2b contains 12 percent less HEMA than 5, it has a faster hydrolysis rate. Even more significantly, the release rate of 2c, which contains 20 percent less HEMA, is also faster.

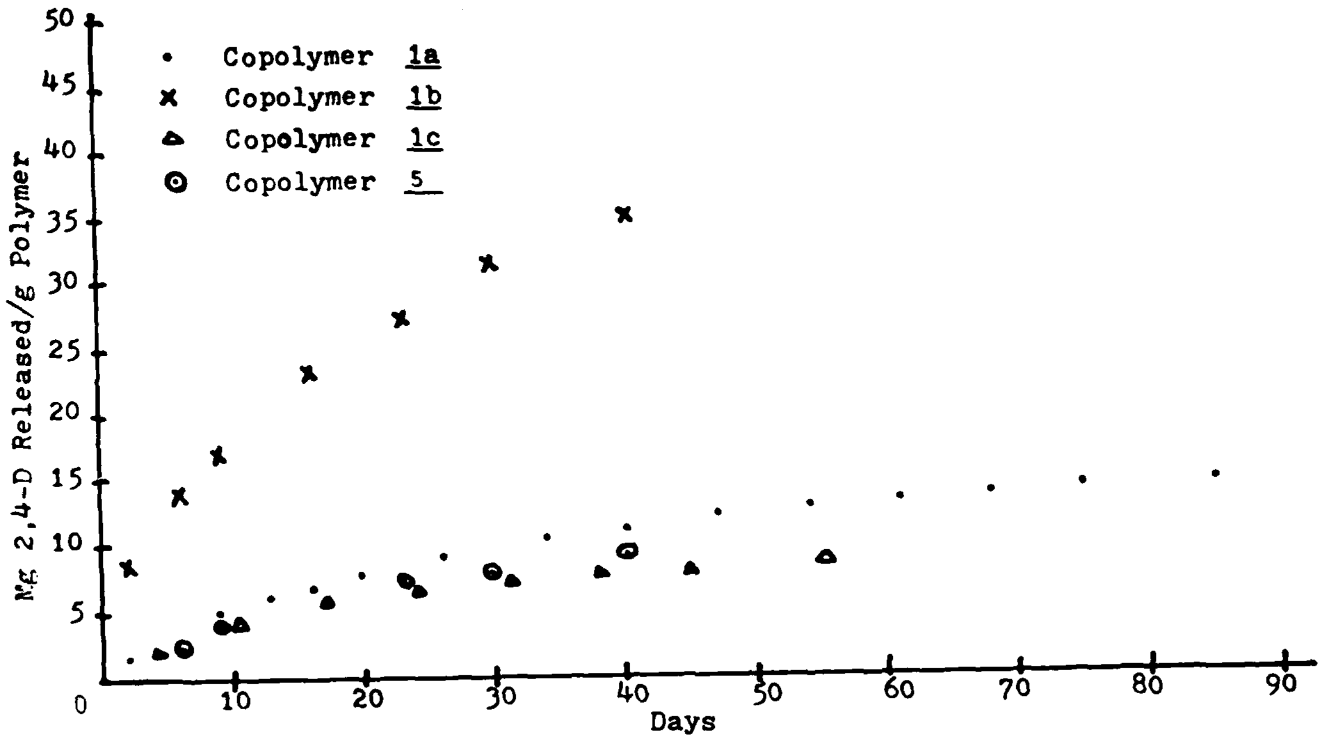

Figure 2. Hydrolysis of AOE 2,4-D/HEMA copolymers: 1a-1c and 5

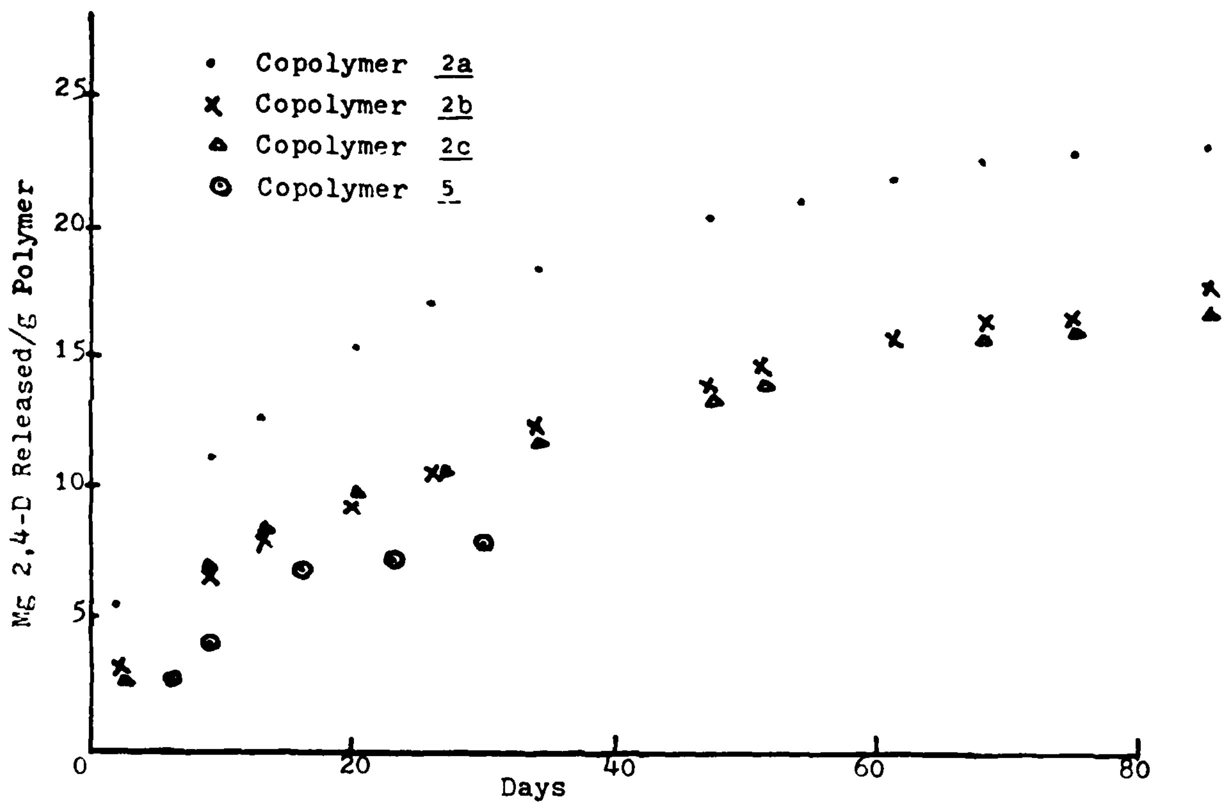

Figure 3. Hydrolysis of AOE 2,4-D/HEMA copolymers: 2a-2c and 5

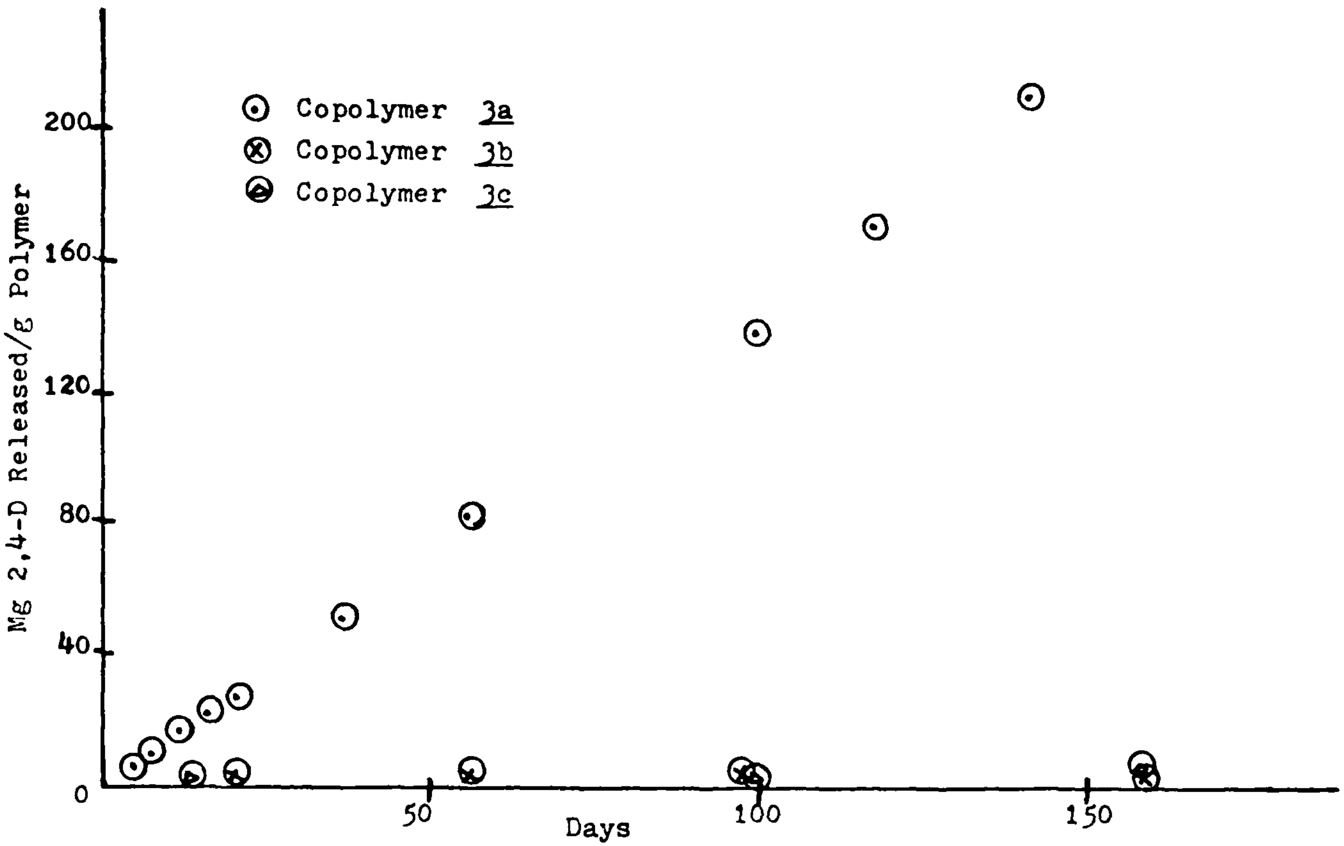

Figure 4. Hydrolysis of MOE 2,4-D/GMA copolymers: 3a-3c

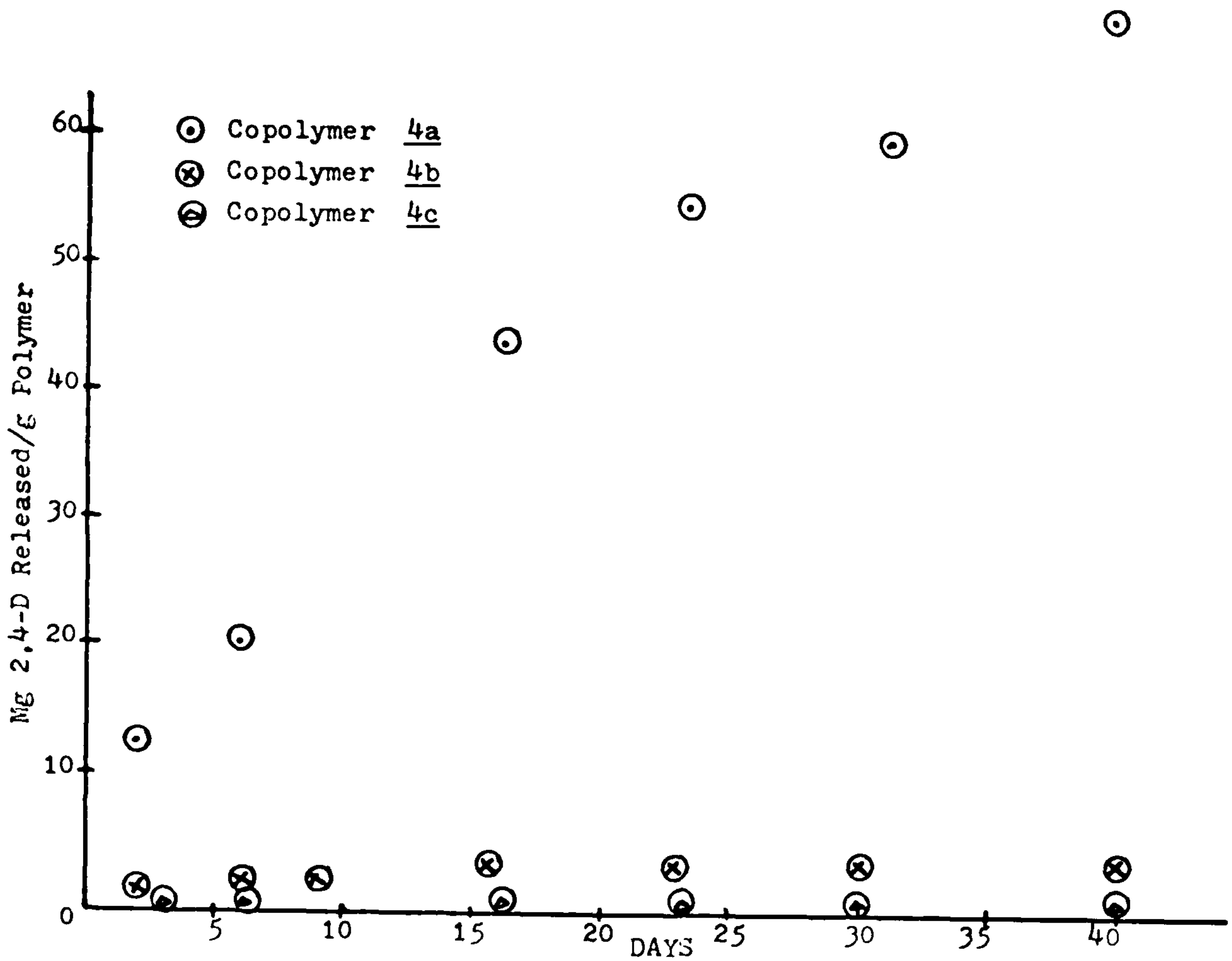

Figure 5. Hydrolysis of MOE 2,4-D/GMA copolymers: 4a-4c

The release rates of MOE 2,4-D/GMA copolymers prepared by programmed-addition techniques were also faster than those of analogous copolymers prepared by batch procedures. For example, copolymer 4a, which has the same composition as copolymer 3a, released 55.5 mg of 2,4-D in 23 days, whereas 3a released only 33 mg in this same time period (Figures 4 and 5).

The hydrolysis rates for the MOE 2,4-D/GMA copolymers which contain less than 50 percent HEMA are extremely slow even when produced by programmed-addition techniques. Apparently, these copolymers are still not hydrophilic enough to undergo significant hydrolysis.

The MOE 2,4-D/EPMA copolymers did not undergo hydrolysis in the hard water solutions. Evidently, the epoxy ring contained in EPMA did not impart enough hydrophilicity to the copolymers to permit hydrolysis. The ring also must not have undergone any appreciable amount of ring opening in the hydrolysis solutions.

Scale-up of monomer syntheses

Approximately 200 lb of technical 2,4-D acid was obtained from Union Carbide. This material was converted to the corresponding acid chloride by treatment with thionyl chloride. Several sodium-hydroxide traps were needed to neutralize the copious amounts of hydrogen chloride gas that evolved. The acid chloride was purified by distillation under reduced pressure.

Considerable effort was devoted to the scale-up of the synthesis of MOE 2,4-D. Several problems were encountered in this work. For example, after the reaction between the acid chloride of 2,4-D and HEMA is stopped, the reaction mixture is extracted several times to remove unreacted lutidine. During these extractions, relatively stable emulsions form, thereby greatly delaying the extraction process. The yields of MOE 2,4-D are also only fair, ranging from 40 to 50 percent. The reaction was carried out under several different sets of reaction conditions in an attempt to alleviate these problems. It appears that the extraction emulsions can be avoided and the yield of MOE 2,4-D increased by decreasing the concentration of reactants and increasing the time of reaction. Apparently, the increase in the amount of solvent used aids the reaction of the intermediate 2,4-D/lutidine salt with HEMA by permitting more of the salt to remain in solution.

In order to completely avoid the extraction procedure, the replacement of lutidine with molecular sieves was investigated. (Powered 3Å sieves have been reported to effectively absorb hydrogen chloride.) Thus, the reaction of the acid chloride of 2,4-D with HEMA was carried out over powdered molecular sieves in carbon tetrachloride, ether, and ethylene chloride. The yield of MOE 2,4-D ranged from 50 to 75 percent. We did encounter a problem with the rapid moisture uptake of the sieves which resulted in their deactivation. However, the sieves could be reactivated immediately prior to use by drying at 150°C under high vacuum. This procedure, with ethylene chloride as the solvent, was used to prepare approximately 50 lb of the monomer.

An extensive effort was made to develop a purification procedure for large amounts of MOE 2,4-D. Several attempts were made to recrystallize the monomer from organic solvents. However, the monomer either completely failed to crystallize or crystallized very slowly (1 to 2 weeks). Although small amounts of pure materials were obtained, attempts to distill the monomer under high vacuum resulted in considerable decomposition. A copolymerization of the impure MOE 2,4-D with GMA was carried out to determine if purification could be avoided. The polymerization, however, gave only a small amount of low molecular weight material.

The synthesis of GMA from EPMA was scaled up to provide approximately 50 lb of material. The monomer was extracted with ether to remove unreacted starting material.

Scale-up of polymer syntheses

An investigation of the scale-up of a 50:50 MOE 2,4-D/GMA copolymer was carried out. Several problems with fortuitous gellation were encountered. Cross-linking was avoided by carefully controlling the concentration of the reactants. Approximately 10 lb of the copolymer was prepared and submitted for preliminary field testing.

Due to the danger of explosion associated with handling large quantities of hot methyl ethyl ketone, the use of the considerably less volatile solvent methyl cellosolve was investigated. Copolymerizations in this solvent gave good yields of the desired copolymer.

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Table 1

AOE 2,4-D/HEMA Copolymers

Polymer No.	Desired Composition AOE 2,4-D:HEMA	Initial Feed Ratio AOE 2,4-D:HEMA	Reaction* Time hr	Yield Percent	Percent Cl	Tg** °C	η†	Copolymer†† Composition AOE 2,4-D:HEMA
1a	50:50	71:29‡	5	70	16.70	22	0.22	55:45
1b	34:66	56:44‡	4	43	13.70	25	0.33	39:61
1c	66:34	83:17‡	4	75	19.62	20	0.15	75:25
2a	50:50	80:20‡‡	4	52	15.65	19	0.26	49:51
2b	60:40	86:14‡‡	4	57	17.15	19	0.19	58:42
2c	70:30	90:10‡‡	4	42	18.21	14	0.18	65:35

* One-hour interval between programmed additions.
** Determined from differential scanning calorimeter data.
† Inherent viscosity (0.50 g/dl in DMF at 30°C).
†† Determined from chlorine analysis.
‡ 10 percent of initial feed added at each interval.
‡‡ 25 percent of total HEMA added initially and at each interval.

Table 2

MOE 2,4-D/GMA Copolymers

Polymer No.	Initial Feed Ratio MOE 2,4-D:GMA	Reaction Time hr	Conversion Percent	Percent Cl	Tg* °C	η**	Copolymer Composition† MOE 2,4-D:GMA
3a	50:50	24	65	13.94	52	0.33	48:52
3b	70:30	24	61	17.85	42	0.16	71:29
3c	90:10	24	43	20.78	34	0.16	95:5
4a	80:20††	5‡	22	13.99	54	0.21	48:52
4b	90:10††	5‡	25	18.13	48	0.29	73.27
4c	97:13††	5‡	37	19.69	30	0.17	86:14

* Determined from differential scanning calorimeter data.
** Inherent viscosity (0.50 g/dl in DMF at 30°C).
† Determined from chlorine analysis.
†† 25 percent of total GMA added initially and at each interval.
‡ One-hour interval between programmed additions.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Field Evaluation Objectives and Plans for Controlled-Release Herbicides

by

Ronald E. Hoeppel*

Introduction

The Aquatic Plant Control Research Program's (APCRP) Chemical Control Technology Development Project (CCTDP) has planned its scope of work around six tasks. These tasks are discussed in detail in the 14th Annual Meeting Proceedings.** Controlled-released (CR) herbicides, developed in Task II, will be emphasized in FY 81. In-house research will include greenhouse evaluations of low-level chronic doses of select herbicides on target aquatic plants (Task III). The primary objective is to determine the constant-rate threshold herbicide concentration in the water column that provides for regrowth control of specific nuisance aquatic plants. These studies will provide pertinent information for determining field application rates of CR herbicides and in assisting formulators in determining optimal herbicide release rates. Additionally, three field evaluations of CR herbicides (Task IV) are planned for FY 81 as follows: (a) Lake Seminole, Florida; (b) Gatun Lake/Chagres River, Panama; and (c) Lake Osoyoos/Okanagan River, Washington.

Greenhouse Threshold Concentration Study

Background

The effectiveness of regrowth control on select target aquatic plants by herbicides is dependent upon aquatic environmental factors (i.e., light, temperature, pH, water hardness, suspended solids, and nutrient status) as well as on the physical state and growth phase of the target aquatic plants. Due to these complications, herbicides are often applied at rates higher than necessary to effect control under even the most difficult circumstances. The development of CR herbicide formulations that provide low-level chronic herbicide release to target

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

** Westerdahl, H. E. 1980. "An Overview," Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, Miscellaneous Paper A-80-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

aquatic plants requires research to determine the minimum herbicide concentrations required for controlling plant growth during long-term exposure.

Purpose and scope

The purpose of the proposed research is to determine minimum sustained herbicide concentrations required to control regrowth of select aquatic plants. This research will use the actual herbicidal agent rather than the commercial or CR formulation as is currently being done at the U. S. Department of Agriculture, Aquatic Plant Management Laboratory (APML). It is felt that data generated from this work, when combined with available herbicide release-rate data for each CR formulation, will provide quicker and more accurate estimates of field application rates. This additional information should permit immediate testing of promising CR formulations for efficacy in outdoor pools at the APML prior to conducting small-scale field studies. The proposed work is complementary with ongoing laboratory efficacy evaluations of herbicides being conducted at the APML. If successful, expensive and duplicative laboratory-scale evaluations currently being conducted at the APML for each CR formulation will not be necessary prior to testing in outdoor pools.

The specific objective is to determine the optimum sustained threshold concentration of each selected herbicide for regrowth control of specific target aquatic plants; also to elucidate the major plant physiological effects (e.g., leaf, shoot, and root degradation) caused during low-level chronic exposure of each herbicide to different actively growing aquatic plants. These rates will be used as guidelines for the development of CR herbicide formulations in the future and also for estimating reasonable field application rates. In addition, the laboratory system will be evaluated for future assessment of the effects of chronic herbicide exposure to nontarget aquatic organisms; this study phase is planned for FY 82.

Experimental design

The target aquatic plants selected for this study include: Eurasian watermilfoil (*Myriophyllum spicatum*), hydrilla (*Hydrilla verticillata*), and American pondweed (*Potamogeton nodosus*). Rooted meristematic sections, root crowns, and propagules from the plants will be tested. Experiments will be conducted in a controlled-environment greenhouse to accomplish the research objectives. A variable flow-rate, continuously flowing water system will be used in this work; optimum light and constant water temperature will be provided for normal growth of the aquatic plants. A proportional diluter system, similar to the modified Mount and Brungs diluter, will be installed to meter different concentrations of a specific herbicide into each test vessel. The herbicides added to the water will be maintained at a constant concentration throughout each experiment. At the completion of the research, the data will permit determination of the optimum chronic herbicide concentration required for regrowth control of each of the aforementioned aquatic plant species and an assessment of the herbicidal effects on each target plant. A list of the qualitative physiological parameters to be

evaluated during herbicide efficacy testing of the aquatic plants is given in Table 1; these parameters will be given a ranking from 1 (no effect) to 10 (complete effect), using the same methodology developed by the APML. Probit analysis will be used to analyze response functions of plants to herbicides. Laboratory data will be compared to field data collected from the proposed field studies during FY 81.

Five herbicide formulations will be selected for this research plan. All are currently registered or being considered for aquatic use. The herbicide formulations include 2,4-D acid, diquat, potassium salt of endothall, fluridone, and terbutryn. The application rates of selected herbicides are listed in Table 2. The plant exposure period to each herbicide concentration will be 12 weeks, which is adequate for noting efficacy of the herbicides at each rate.

A standard hydrosoil containing 70 percent sand, 20 percent Michigan peat, and 10 percent processed cow manure will be used in the research plan. Twelve 300-ml glass beakers will be placed in each of 24 glass test aquaria. Each beaker will contain 250 g of hydrosoil into which six plant meristematic cuttings or other reproductive propagules will be planted.

Reconstituted soft and hard water (pH of 7.2 and 8.0, respectively) are being used to determine herbicide release rates from each CR formulation in the aquatic plant herbicide evaluation program at the USDA-APML in Fort Lauderdale, Florida. Because of the expense associated with using an artificial water medium, an uncontaminated aged and filtered tap water will be used initially as a water source. The water supply will be tested periodically to determine its chemical quality. An artificial water medium devoid of phosphorus will be used if excessive algal growth interferes with test results during the pilot study.

The aquatic plant propagules to be used in these studies are: tubers or turions, meristematic cuttings (top 15 cm), and root stocks. A 2- to 4-week establishment period for the propagules in the aquaria will precede the herbicide treatments. Different plant species and propagules of a given plant species will be evaluated concurrently in each aquarium.

Figure 1 depicts a functional test aquarium. The water level in each 70-ℓ capacity vessel will be maintained at a minimum of 50 ℓ of water. Herbicide concentrations in the reaction vessels will be precisely controlled with metering pumps injecting herbicide into a modified Mount and Brungs diluter system. All treatments will include three replicates: three blank control aquaria (no herbicide added) will include plants and hydrosoil; three herbicide-treated (0.2 mg/ℓ concentration) aquaria will contain only hydrosoil; and there will be three aquaria for each of the four herbicide treatment rates (Table 2). The remaining six aquaria will be devoid of plants and hydrosoil; each will be treated with the following constant herbicide concentrations: 0, 0.01, 0.05, 0.1, 0.2, and 0.2 mg/ℓ. Overflow from each aquarium will pass through an activated carbon filter prior to being discharged to the sewer system.

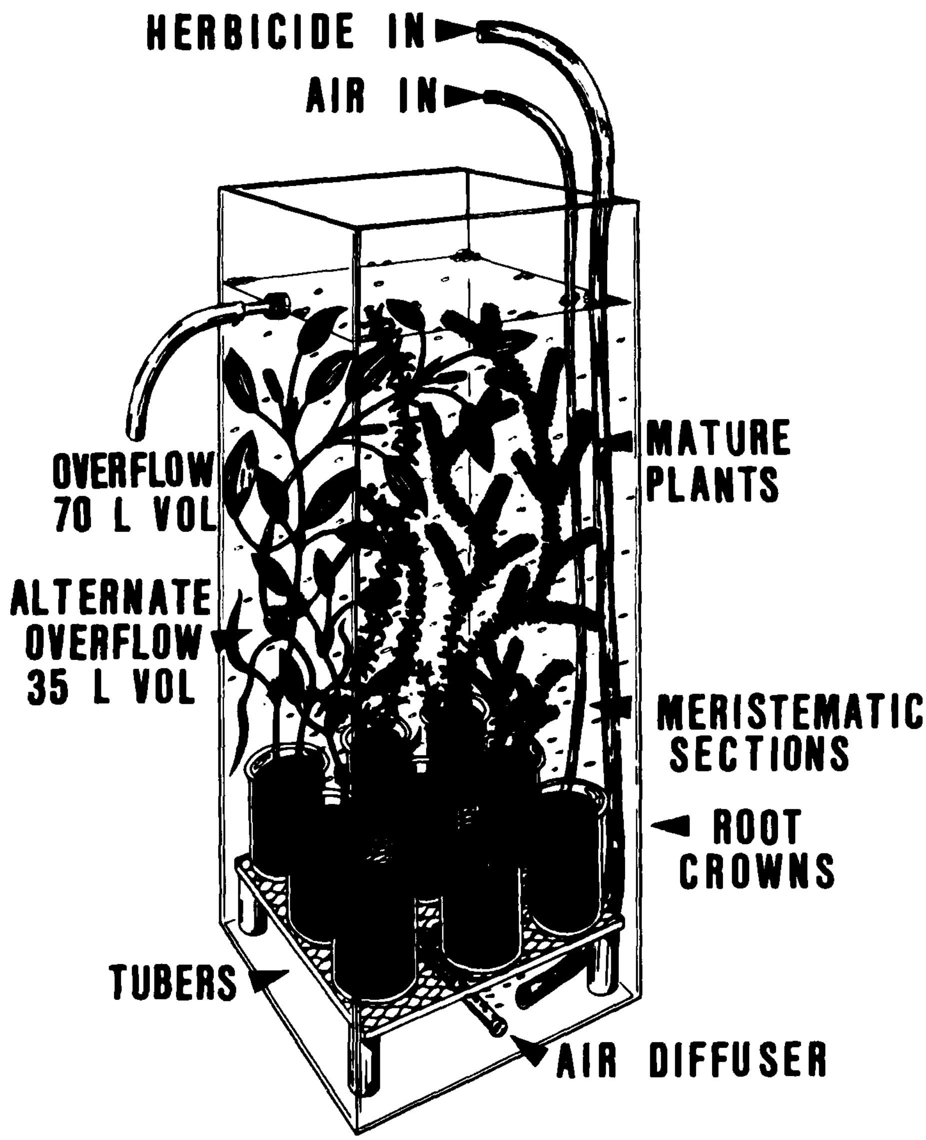

Figure 1. Schematic of a 70-ℓ glass aquarium used as a test reaction vessel

The proposed research will be conducted in a constant temperature (27° ± 2°C) greenhouse environment. Lighting conditions will include a 12- to 14-hr photoperiod. A Sunbrella light bank, containing sodium and multivapor high intensity discharge lamps, will be used as the primary light source. Ambient light will be monitored using a Lambda PAR meter.

All chemical analyses will be performed using approved, standard procedures developed by the EPA and the respective chemical companies manufacturing each chemical. The temperature, dissolved oxygen (DO), pH, and conductivity of the water will be measured weekly. Regrowth of the aquatic plants will be determined by weekly stem length measurements; wet and oven-dry plant weights will be determined at the end of the study. Water samples from each vessel will be collected from the outflow for herbicide residue analyses before and at 3, 7, 14, 28, 56, and 84 days after addition of the selected herbicides. Sediment and plant samples will be collected at the end of the experiment and analyzed for herbicide residue to assist in determining whether or not the herbicide was taken up by the plants or adsorbed to the sediments.

Only one herbicide will be tested and reported on this year, namely 2,4-D. Diquat or fluridone testing will commence before the end of FY 81, provided that funds are available for chemical analyses.

Lake Seminole Field Test

Purpose

The proposed CR herbicide testing will be conducted in watermilfoil beds in Lake Seminole, on the border of Georgia and Florida. Its purpose is to evaluate two experimental 2,4-D CR formulations developed to prevent watermilfoil regrowth, namely, 2,4-D MOE/GMA in clay pellets and 2,4-D acid in pelletized Kraft lignin residue. The 2,4-D MOE/GMA formulation is being produced under contract by Wright State University in Dayton, Ohio, and the 2,4-D acid/lignin product is supplied by Westvaco, Inc., in Charleston, South Carolina. Neither formulation has been tested under field conditions. The results of this study will provide guidance for any future operational studies with these CR formulations.

Scope

The proposed test will involve an initial treatment of five field plots with Aquathol K plus Nalquatic to provide rapid knockdown of the existing watermilfoil. The Nalquatic is an adjuvant which binds herbicides to the surface of the foliage. The two CR 2,4-D formulations and conventional 2,4-D (DMA) will then be applied to five individual plots to study their efficacy toward deterring watermilfoil regrowth. One plot will be treated only with the Aquathol K plus Nalquatic to evaluate regrowth in the absence of 2,4-D herbicide treatments. One plot will be treated only with the CR 2,4-D/lignin product (no initial application of Aquathol K - Nalquatic for initial knockdown) to evaluate the

efficacy of a single treatment with the CR formulation on both the initial knockdown and regrowth inhibition of watermilfoil.

The CR formulations are designed to prevent regrowth of nuisance aquatic plants by continually releasing very low levels of active herbicide into the water. Since these formulations and the released 2,4-D acid will be in close proximity to the watermilfoil roots and viable propagules, it is anticipated that most of the herbicide will be rapidly taken up by the plant biomass or fixed in the upper soil layer in proximity to the roots. The 2,4-D maintains its effectiveness even when bound with the sediment.

Laboratory evaluations by Water and Power Resources Service in Denver, Colorado, have shown that constant (zero order) release of less than 0.03 ppm 2,4-D acid is effective in killing watermilfoil. The 2,4-D MOE/GMA provides almost constant release of 2,4-D acid into the water column, providing a concentration of approximately 0.03 ppm in a flowing water, 1-ha plot 2 m deep that receives an application rate of about 135 kg/ha of the CR formulation (68 kg/ha 2,4-D acid equivalent). The 2,4-D acid/lignin formulation also appears to release the herbicide at a similar rate. The release rate from the lignin pellets is about 1 mg of 2,4-D acid per gram of product per day, for more than 6 months.

The CR herbicide formulations should provide long-term control of watermilfoil for periods greater than 6 months. Therefore, two annual treatments, initially with a conventional herbicide and followed 1 month later by application of a CR formulation, should provide complete control of the nuisance aquatic plants for the duration of the growing season or perhaps provide for total kill in the treatment areas. A lignin pellet mixture, containing both pelletized 2,4-D acid and 2,4-D (DMA), is presently being prepared by Westvaco. Lignin pellets containing 2,4-D (DMA) have shown initial high burst releases of the herbicide while those containing 2,4-D acid show only a negligible initial burst release. If this anticipated combination formulation is available, it will be applied to the plot not receiving pretreatment with Aquathol K. The high initial release of 2,4-D (DMA) followed by a slow constant release of 2,4-D acid may make this formulation useful for both initial knockdown and regrowth control of watermilfoil.

Study plan

The field study is planned to commence in April 1981. The study plan entails the application of herbicides to six field plots, each less than 1 ha in size. One reference plot, receiving no herbicides, will be selected to observe the natural growth of the aquatic plants during the study. Five of the plots will be initially treated with Aquathol K plus Nalquatic to elicit initial knockdown of the standing crop. Application will be with weighted trailing hoses or newly developed surface application equipment for Nalquatic mixtures. The plots will be in areas of Lake Seminole which have not recently been treated with herbicides.

The six plots will be treated as follows: (1) Aquathol K plus Nalquatic; (2) Aquathol K plus Nalquatic followed by treatment with

conventional 2,4-D (DMA) at the prescribed dose; (3) Aquathol K plus Nalquatic followed by application of the 2,4-D MOE/GMA formulation at a rate of 70 kg/ha 2,4-D acid equivalent (approximately 700 kg/ha of the clay pellet product); (4 and 5) Aquathol K plus Nalquatic followed by application of the pelletized 2,4-D acid/lignin formulation at two rates, namely, 35 and 70 kg/ha 2,4-D acid equivalent (approximately 70 and 140 kg/ha of the lignin pellet product); and (6) one plot treated solely with a combined 2,4-D acid--2,4-D (DMA)/lignin formulation or with the 2,4-D acid/lignin formulation at the high rate (70 kg/ha 2,4-D acid equivalent). The 2,4-D treatments will be applied following removal of the standing crops with Aquathol K, which should require about 3 to 4 weeks. Appropriate approvals from the EPA have been received for application of these CR formulations in field studies.

Water, plant, and surface sediment samples will be collected from all plots before herbicide treatment. Additional bottom water and plant samples will be collected at approximately 0, 1, 2, 4, 6, 8, 10, 12, and 14 months after application of the CR and conventional 2,4-D acid formulations. Water samples will be collected regularly and analyzed until the levels are below detection limits (0.001 ppm) or background concentrations. Following watermilfoil regrowth in the plots, an additional complete set of sediment samples will be collected from all plots to determine if an accumulation of 2,4-D had occurred. Interim sediment sampling will be conducted periodically to determine if movement of the CR formulation from the areas of application had occurred. Visual and photographic monitoring of the plots will be the primary method for determining treatment efficacy. In addition to visual monitoring, a fathometer with a narrow angle transducer will be used to semiquantitatively determine the extent and rate of watermilfoil regrowth in the plots.

Lake Osoyoos/Okanagan River Field Test

Purpose

This field test will be conducted in Lake Osoyoos and in the Okanagan River between Lake Osoyoos and Vosel Dam at Oroville, in north central Washington. The plots in the lake will be primarily experimental in design and will evaluate the efficacy in a cold water lake of two CR herbicide formulations, 2,4-D MOE/GMA and 2,4-D acid in lignin pellets; these data will later be compared with the findings obtained from the warm water Lake Seminole study, which will be treated with the same CR formulations. The Okanagan River will be treated with the 2,4-D MOE/GMA formulation. Since conventional herbicides cannot presently be applied to river systems, the Okanagan River application will be operational in scope but experimental in design.

The spread of Eurasian watermilfoil from Lake Osoyoos into the Okanagan River has created the potential for serious watermilfoil infestations in many recreational and hydroelectric impoundments of the lower

Columbia River system. Shallow water conditions in the river preclude conventional mechanical harvesting. Permission has been granted by the EPA to treat up to 2.5 ha of flowing water at this site with CR herbicide formulations. Thus, this CR herbicide application is urgently needed to suppress or eliminate the established watermilfoil growth in the Okanagan River.

Scope

There are three field plots planned for this study. Two plots in Lake Osoyoos will be treated initially with Aquathol K plus Nalquatic to provide initial kill of the standing watermilfoil crop. Following knockdown, the plots will be treated with the 2,4-D MOE/GMA and 2,4-D acid/lignin pellet formulations, respectively. The river plot will be treated solely with one rate of the 2,4-D MOE/GMA formulation following hand removal of the watermilfoil within the treatment area.

Study plan

The field study at Oroville is planned for late June 1981, following the salmonoid fish migration season. The two lake plots and one river plot will each be less than 1 ha in size. The estimated infested area in the river is about 5 ha, but most of the infestation lies above a screen barrier installed across the river. The initial treatment area will thus probably be in the infested areas below this barrier and above the confluence of the Okanagan and Skilkomene Rivers. The lake plots will be cleared of aquatic plants by an initial application of Aquathol K mixed with 1.5 percent Nalquatic adjuvant. Following knockdown of the standing crop, each lake plot will be treated with either the 2,4-D MOE/GMA formulation (35 kg/ha 2,4-D acid equivalent) or the 2,4-D acid in lignin pellets (70 kg/ha 2,4-D acid equivalent). The river plot will be treated with one rate of the 2,4-D MOE/GMA formulation (70 kg/ha 2,4-D acid equivalent) following hand harvesting of the watermilfoil. The above rates are based on previous release-rate data for these CR formulations. However, ongoing laboratory screening results, as well as preliminary field data from the Lake Seminole study, may necessitate varying the application rates to provide maximum control at minimal application rates.

Herbicide residue and water quality monitoring will be conducted before the herbicide treatments and at 1, 7, 28, 56, 84, 145, 265, 325, and 385 days following application of the CR formulations. Visual, photographic, and fathometer monitoring of the treated plots will be conducted to estimate the rate of watermilfoil regrowth following the CR herbicide treatments.

Gatun Lake/Chagres River Field Test

Purpose

The proposed test will be conducted in Gatun Lake and the mouth of

the Chagres River, Panama. Its primary purpose is to further evaluate the two endothall products used for hydrilla control during 1979 in Gatun Lake, namely, Aquathol K and Hydout. A new dust-free pelletized Hydout formulation will be evaluated. Aquathol K will be compared to a mixture of Aquathol K and Nalquatic; the Nalquatic is a polymeric inert binder used to promote greater herbicide contact with the target aquatic plants.

The previous year's study noted a very rapid and efficient knockdown of the hydrilla standing crop in the Aquathol K plots, whereas the Hydout plots showed a much slower plant knockdown rate. However, significant hydrilla regrowth within the Hydout plots was not observed for 4 months while the hydrilla in the Aquathol K plots had become almost completely reestablished within the same time frame. Some of the pelletized Hydout sank into the organic muck, where it appeared to elicit a slow release of the endothall acid. In contrast, the liquid Aquathol K formulation produced an initially high concentration of the endothall acid throughout most of the immediate water column but it provided for only a short contact time with the plant biomass compared to the Hydout pellets.

Operational studies with Aquathol K and Hydout in dredged material disposal areas in Gatun Lake and the mouth of the Chagres River were conducted by the Panama Canal Commission (PCC). They observed only marginal kill of hydrilla at approximately twice the application rates found to be effective in the previously mentioned study. Moreover, the most serious problem encountered with the conventional Hydout formulation was the generation of dust during application, which caused skin irritation to the applicators. Therefore, a new dust-free binder will be tested in place of the clay binder for the Hydout pellets. The Aquathol K formulation was noted to elicit longer term efficacy to watermilfoil in Lake Osoyoos, Washington, when it was initially bound with Nalquatic. Aquathol K liquid will thus be compared to its suspension in Nalquatic to evaluate the adjuvant for hydrilla control in Panama.

Scope

The different release characteristics of the Aquathol K and Hydout can be used in combination to provide a more proficient and cost-effective management technique for long-term hydrilla control. For example, a given treatment area could be treated initially with Aquathol K to provide rapid knockdown of the standing plant biomass. The Hydout could then be applied at a reduced rate to the same treatment area to prevent regrowth from viable meristematic tissue surviving the first treatment.

The results of last year's study indicated that the time required to achieve knockdown of the hydrilla biomass by Aquathol K is about 3 weeks. In contrast, hydrilla biomass in the Hydout plots continued to decrease for about 4 months. It is postulated that hydrilla control can be extended beyond 6 months by applying both the Aquathol K and Hydout to a given area in proper sequence.

Study plan

The field study is anticipated to begin in the summer or fall of 1981. Application of the Aquathol K/Nalquatic mixture to field plots in Gatun Lake and the Chagres River will be with a weighted trailing hose or newly developed application equipment.

Five operational-sized (approximately 3 ha) field plots will be treated initially with an Aquathol K/Nalquatic mixture followed 1 month later with the new Hydout pellet formulation. Four of these plots will be located at dredged material disposal areas in Gatun Lake. Two replicate treatment rates of the dust-free Hydout formulation will be applied to these plots; all four plots will receive the same treatment rate of the Aquathol K/Nalquatic mixture. A fifth plot will be located above the mouth of the Chagres River. This plot will be treated with the high rate of the new Hydout formulation.

Two additional experimental-sized plots in Gatun Lake will be treated with Aquathol K (without Nalquatic) and the new Hydout pellet formulation in a similar manner. These plots will probably be chosen from sites used in the 1979 study. The purpose is to evaluate these two endothall formulations when used in combination. Also, the efficacy of Aquathol K, with or without Nalquatic, can be evaluated and compared.

The primary emphasis of the experimental and operational field plot studies will be to monitor hydrilla response to the treatments. Hydrilla regrowth following the pelletized Hydout treatment will be determined using a fathometer equipped with a narrow angle transducer. The patterns and extent of hydrilla regrowth will be permanently recorded while making a minimum of four transects across each plot. Water quality (i.e., water temperature, conductivity, pH, and dissolved oxygen) will be measured at appropriate intervals with a Hydrolab monitor.

Visual monitoring of the experimental field plots and the operational field sites will be performed routinely by PCC personnel. It is presently anticipated that hydrilla regrowth assessment will be conducted following the Hydout treatment after 4, 28, 84, 170, and 225 days. However, the actual dates will be determined by observations made by PCC personnel.

Table 1

Qualitative Physiological Parameters Observed for the Target Aquatic Plants During Testing

Heavy algal cover	Branch decomposing near tip
Leaves heavily calcified	Main stem decomposing near tip
Roots evident	Branch decomposing throughout
No meristems on main stems	Plants decomposing (general decomposition)
No meristems on branches	Only root material left
Leaves turning red on main stems	Normal growth
Leaves turning red on branches	Very slight deterioration of leaves or stems
Stems brittle	Advanced decomposition (only few stems remain intact)
Plants flaccid	General regrowth in evidence
Partial leaf loss	Evidence on solarizing
Total leaf loss on branch	Complete disintegration of plant material
Internodes decomposing	
Nodes decomposing	

Table 2

Constant-Rate Concentrations Selected for Each Herbicide to be Evaluated

Herbicide Formulation	Threshold Concentration mg/ℓ (Active Ingredient)
2,4-D (acid)	0.01, 0.05, 0.1, 0.2
Diquat	0.001, 0.01, 0.1, 0.5
Fluridone	0.0001, 0.001, 0.01, 0.1
Endothall (K-salt)	0.05, 0.1, 0.5, 1.0
Terbutryn	0.001, 0.01, 0.05, 0.1

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Evaluating Chemicals for Aquatic Plant Control

by

Kerry K. Steward*

As the title of my presentation indicates, our cooperative effort with WES involves research evaluation of herbicides and growth regulators for efficacy in managing aquatic plant growth.

As members of the public, we are concerned over potential adverse environmental impact in the use of chemicals in water. We, consequently, are aware of the need to discover safer and more effective tools which we must use in order to meet the responsibilities of managing our water resources.

The first step in a search for new chemical tools is synthesis. The next step is an evaluation process using weed species for which control is desired. This evaluation procedure involves culture of various weed species under artificial environments in order to produce optimum growth. Once the efficacy of a chemical against a particular species has been determined, attempts to improve performance or safety can be initiated through innovative formulation techniques.

Several recently developed techniques of formulating effective chemicals, such as 2,4-D, within various polymers or matrix structures to provide controlled release (CR) over time appear to hold great promise for maintaining control of regrowth of susceptible species.

Research evaluation systems for conventional herbicide formulations were designed to evaluate their effectiveness at fixed concentrations under static conditions. New evaluation techniques will need to be developed for CR formulations since these formulations will be designed to deliver chemicals over extended periods of time at predetermined rates.

Workshop on Evaluating CR Herbicides

Recognizing the need to modify existing aquatic herbicide evaluation techniques, a workshop was held 7-8 November 1979, at Fort Lauderdale to discuss development of protocol for evaluating CR herbicides. It was agreed that uniform procedures should be established to facilitate interlaboratory comparisons.

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It was also agreed that uniform plant culture conditions should be established where possible or be characterized when not possible; for example, quality parameters of local natural water supplies should be described for each laboratory.

The draft protocol described procedures for initial investigation of formulation in the laboratory with investigation of a more advanced nature in outside aquaria for formulations which appeared promising in laboratory investigations.

A consensus was reached among workshop participants that controlled-release herbicide formulations (CRHF) should provide efficacy in control of plant regrowth after initial control has been attained by conventional means.

As a consequence it was also recognized that evaluation of CRHF's should be conducted under conditions of precisely regulated water flow so that reliability and constancy of herbicide release could be determined.

Research Status

Our principal activity this past year has been the development and implementation of protocol for evaluating controlled release formulations of aquatic herbicides. This will be the focus of my presentation today.

All of our work this past year was done in the laboratory and consisted of development of prototype systems and of developing sampling and analytical techniques for herbicide analysis.

MOE 2,4-D/GMA copolymer

One of our first tasks was to determine release rates of CR formulations provided by Dr. Frank Harris's lab. One of the formulations was his MOE 2,4-D/GMA copolymer (2-methacryloyloxyethyl 2,4-dichlorophenoxyacetate copolymarized with glycerylmethacrylate).

Release rates were obtained from the copolymer dispersed in reconstituted water in order to provide interlaboratory comparisons and from our natural water supply from a dug pond on the Agricultural Research Center grounds.

The concentration of 2,4-D in reconstituted water increased with time indicating that release from the formulation had occurred. Regression analysis of the release rate data revealed a significant relationship between release and time as would be expected. The rate of release of the herbicide was estimated to be 3.2 mg 2,4-D per gram of copolymer per day (Figure 1).

The release rate of 2,4-D from the copolymer into natural water was 2.07 mg/g/day, or approximately one third less than into reconstituted water (Figure 2). The factor or factors responsible for the

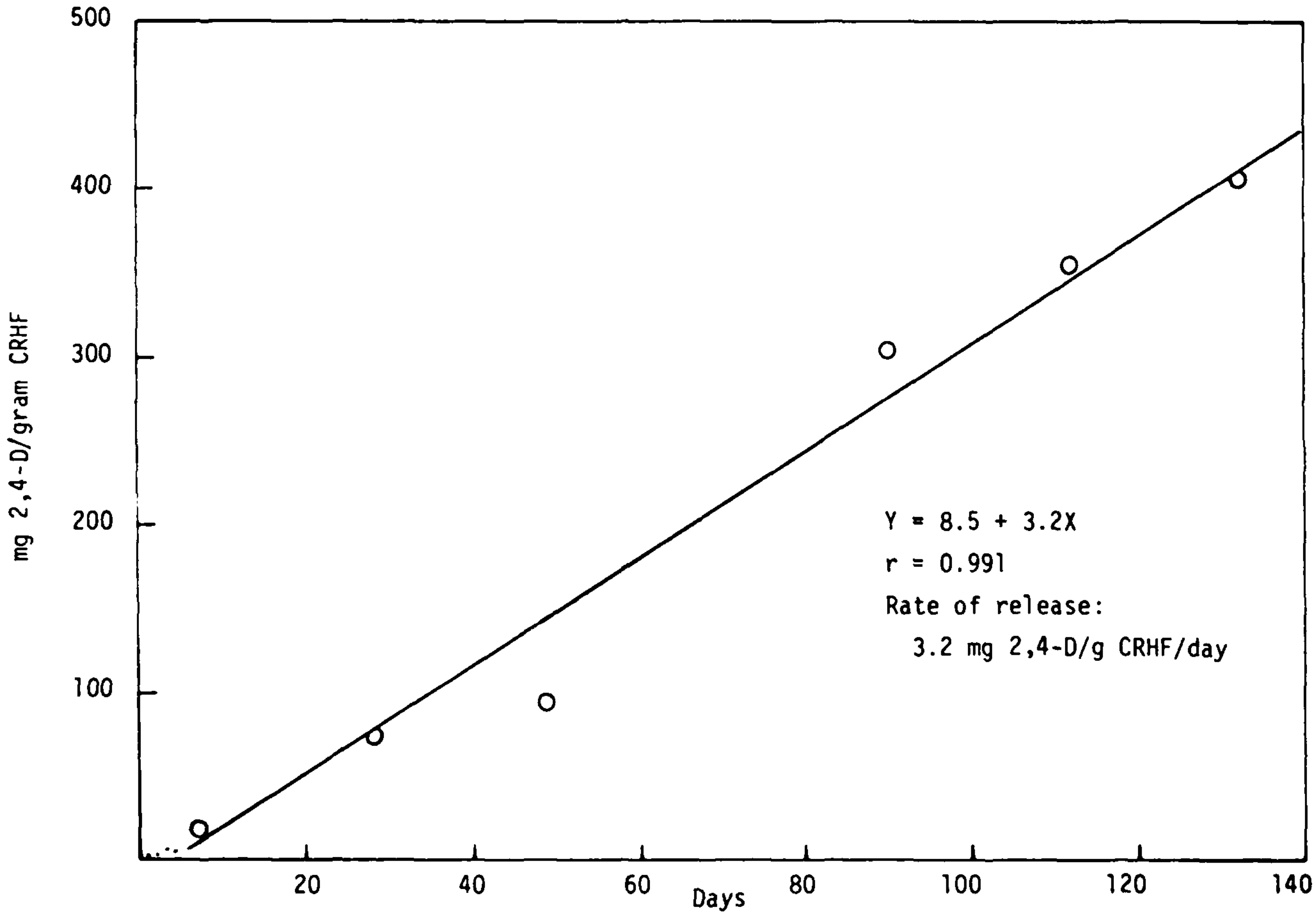

Figure 1. Release of 2,4-D from MOE/GMA CRHF into static reconstituted water

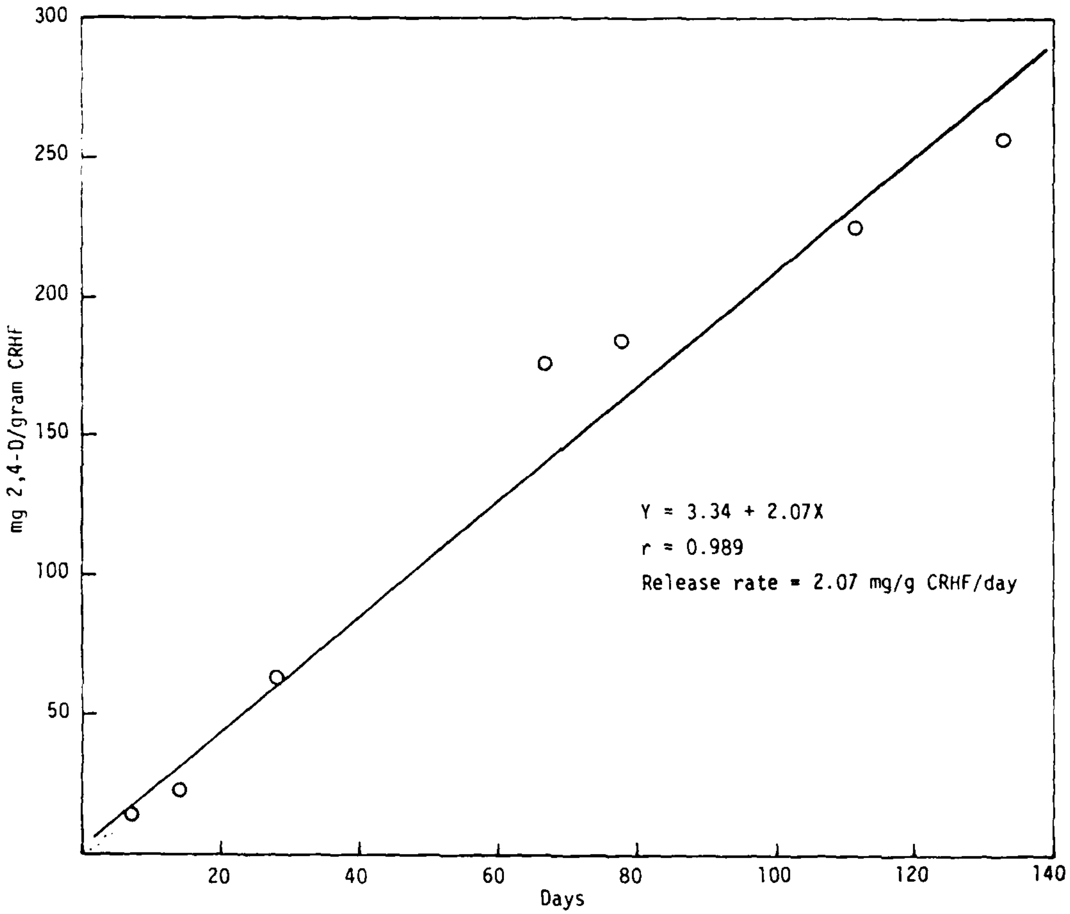

Figure 2. Release of 2,4-D from MOE/GMA CRHF into static natural water

decreasing rate of herbicide release in natural water should be identified so that their effect on field performance of the formulation may be evaluated.

We felt it was necessary to be aware of the stability of 2,4-D in our experimental system. A rapid degradation of 2,4-D as it is released from the CR formulation would confound the determinations of constancy of release from experimental formulations.

Conventional formulation of 2,4-D DMA was applied to static natural water in the lab under controlled light and temperature conditions.

Slow degradation of 2,4-D was observed over the 70-day sampling period. Complete disappearance of the herbicide occurred only in one replicate of each of two treatments: the 50- and 250-μg/ℓ (ppb) treatments (Table 1).

The disappearance of 2,4-D in the two replicates did not appear to be related to concentration but appeared to be random. Disappearance was very abrupt and occurred after 14 days. Scatter diagrams and regression lines of the degradation data show the gradual decline in herbicide concentration with time (Figures 3-7).

The linear regression equations from these analyses were used to estimate the degradation rate of 2,4-D in various treatments. These rates are expressed in three different ways in the following tabulation:

Applied 2,4-D ppb	ppb/day	Percent of Applied per day	Half-Life days
10	0.056	0.56	92
25	0.057	0.23	177
50	0.368	0.70	25
100	0.350	0.36	123
250	1.89	0.76	24

Estimates for the 50- and 250-ppb treatments reflect the influence of the abrupt disappearance of 2,4-D in one of each replicate treatment. The half-lives for the replications in which abrupt degradation did not occur were 743 days for the 50-ppb treatments and 414 days for the 250-ppb treatments.

The results of our investigations indicate that degradation was slow and, considering the short residence time of the chemical in the aquaria under flowing water conditions, the measurements of 2,4-D levels in this system can be considered accurate estimates of release.

Our trials were conducted in 19-ℓ glass containers. Controlled flow of water was provided to each container by multichannel tubing pump. Water flow to individual containers was regulated to provide one complete volume every 24 hr, i.e. approximately 13 ml/min.

Based on the estimated release rate provided by Dr. Harris (1.2 mg 2,4-D/g CRHF/day), we applied treatments to culture vessels with and

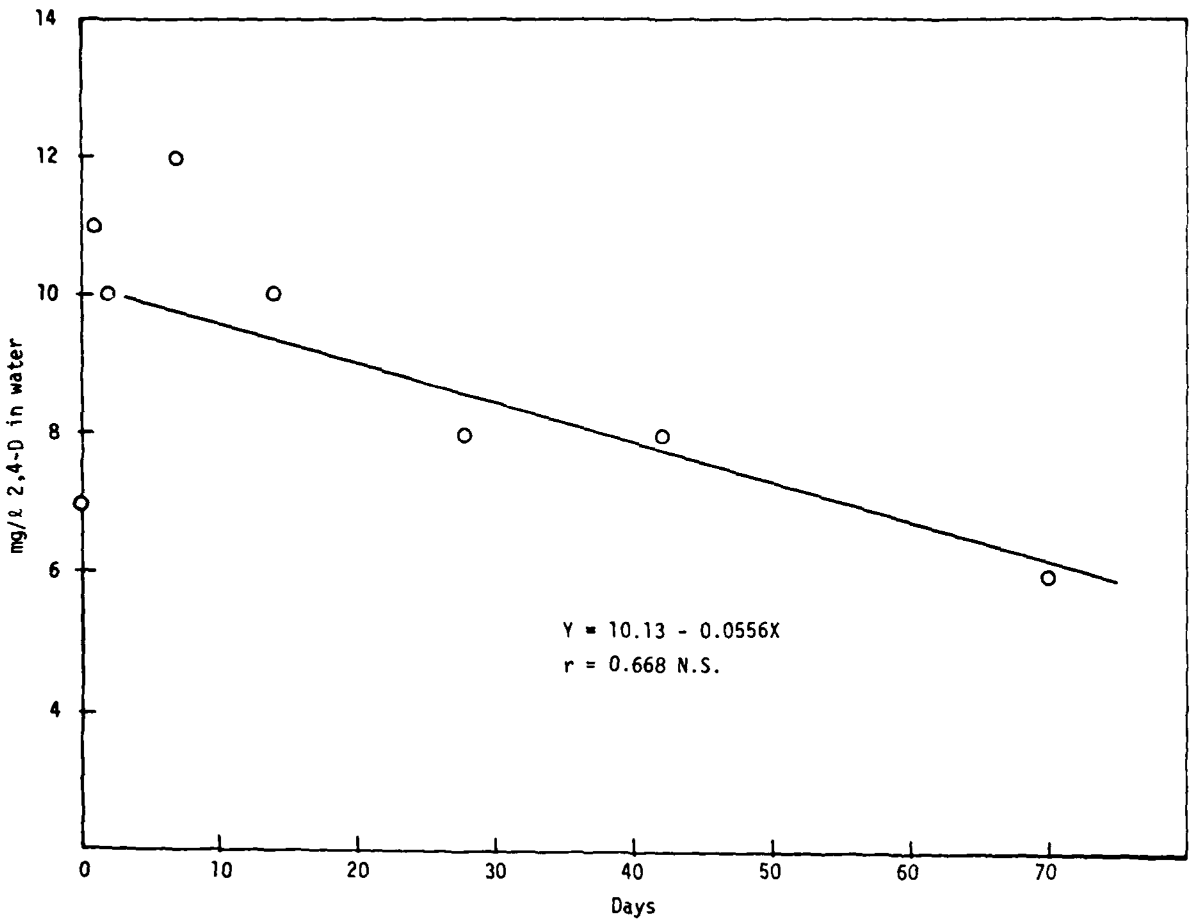

Figure 3. Degradation of 2,4-D in natural water in the laboratory applied at a 10-ppb rate

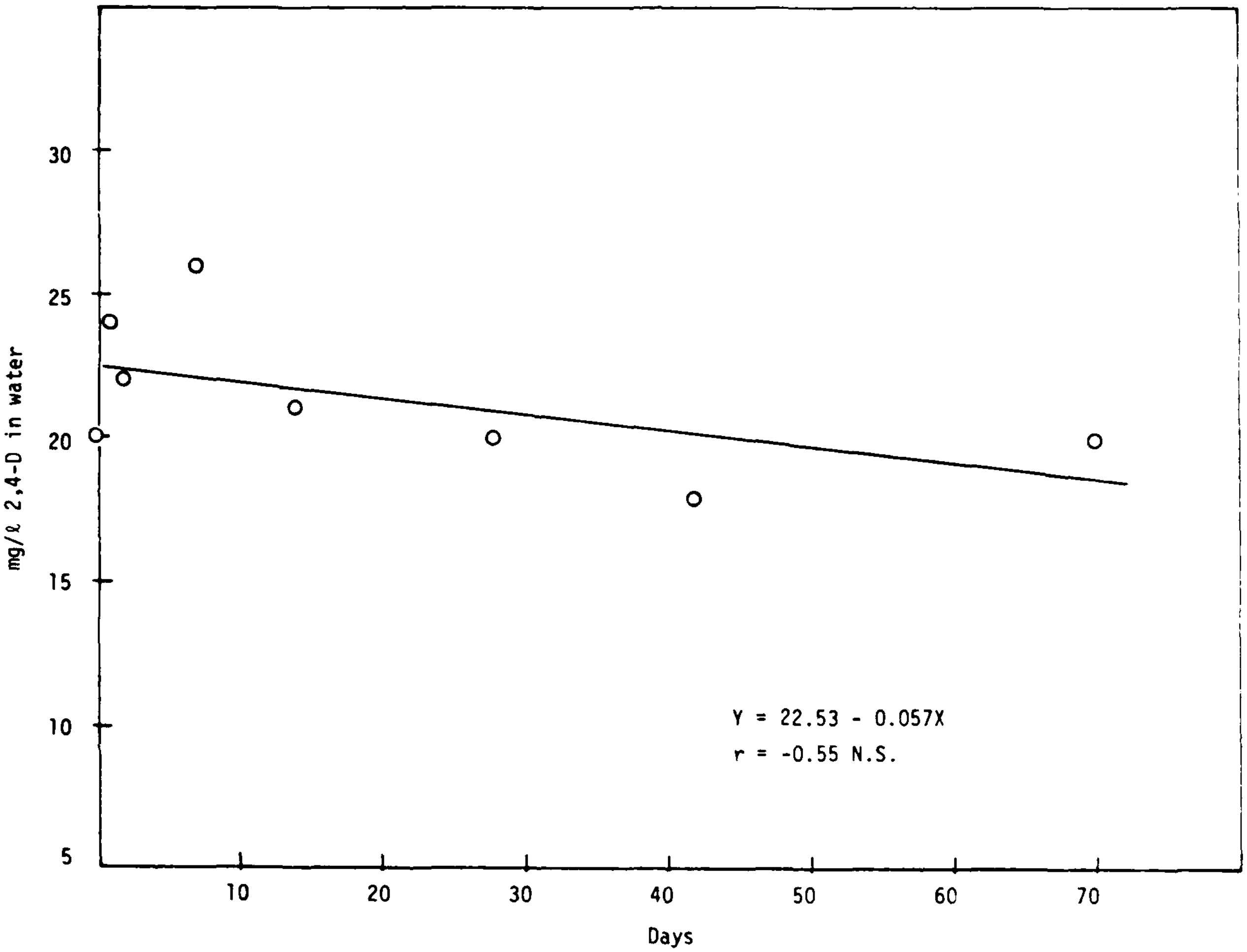

Figure 4. Degradation of 2,4-D in natural water in the laboratory applied at a 25-ppb rate

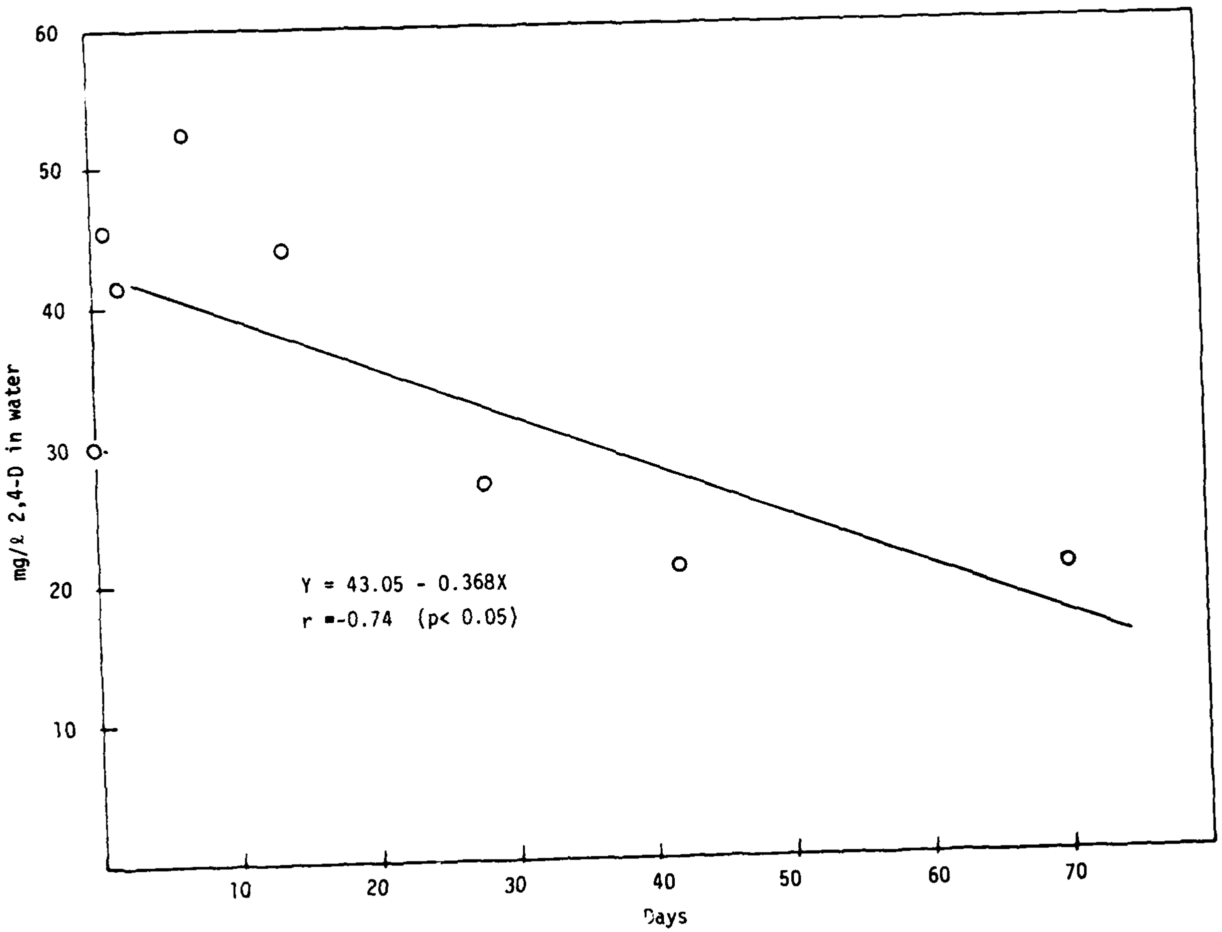

Figure 5. Degradation of 2,4-D in natural water in the laboratory applied at a 50-ppb rate

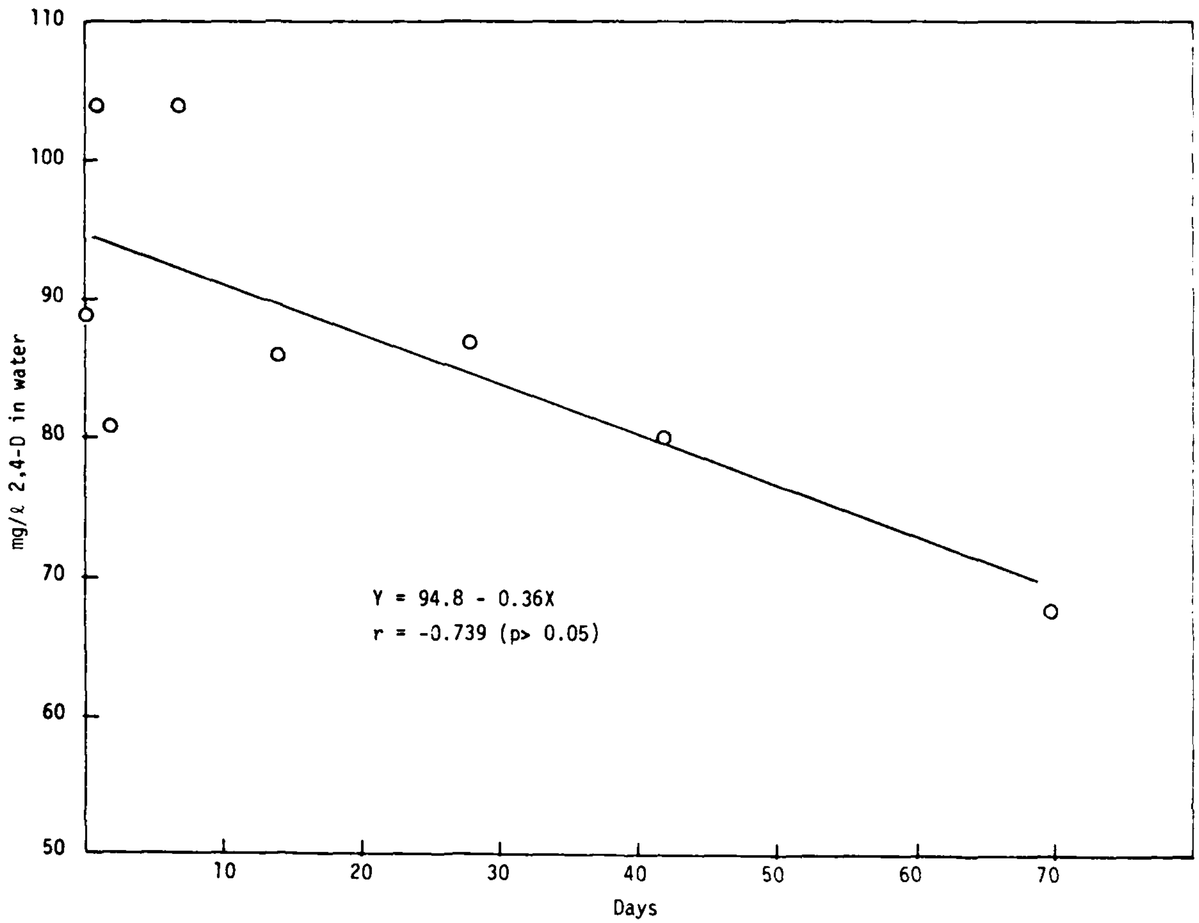

Figure 6. Degradation of 2,4-D in natural water in the laboratory applied at a 100-ppb rate

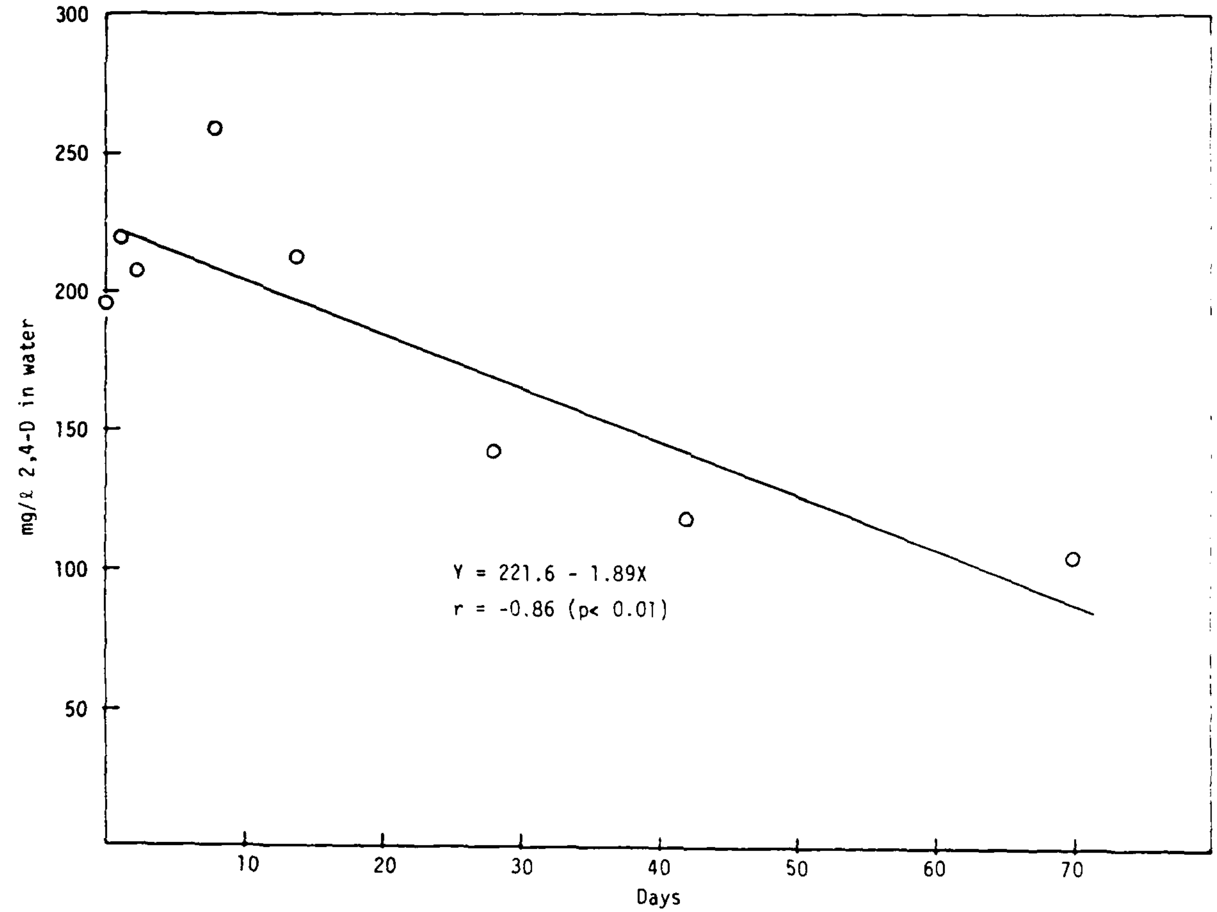

Figure 7. Degradation of 2,4-D in natural water in the laboratory at a 250-ppb rate

without watermilfoil plants at a rate to maintain a 0.1-mg/ℓ 2,4-D concentration in flowing water.

Our objective was to determine constancy of release and efficacy of the formulation in controlling the plants. Results of this trial are reported below.

Figure 8 illustrates the levels of 2,4-D observed over the 56-day time period of the first trial in the absence of plants and soil. Water flow was halted for the first 24 hr to allow 2,4-D concentration to rise to the calculated treatment level of 0.1 mg/ℓ. The actual concentration we observed after 24 hr was 0.2 mg/ℓ. When water flow was resumed, concentration decreased to just above 0.1 mg/ℓ after 48 hr and then increased to 0.3 mg/ℓ after 4 days. Concentration of 2,4-D decreased slightly after 7 days, remained constant up to 4 weeks, and decreased abruptly by 6 weeks. No significant change occurred for the remainder of the trial.

Figure 9 illustrates the observed levels of 2,4-D in water containing watermilfoil plants rooted in soil. Under no-flow conditions, the 2,4-D concentration was nearly 0.2 mg/ℓ after 24 hr. When flow was resumed, 2,4-D levels decreased to approximately 0.1 mg/ℓ after 3 days. Herbicide concentration then increased after 7 days to approximately 0.16 mg/ℓ. Concentration then decreased gradually through the remainder of the 7-week period.

The presence of plants and soil in the containers appeared to decrease the herbicide levels in water by approximately 33 percent when compared to concentrations in containers without plants or soil.

Part of the observed decreases in 2,4-D levels was due to losses of portions of the formulations when discharge flow was obstructed and containers overflowed. System modifications have eliminated this source of variability.

The phytotoxic response of watermilfoil plants to the CRHF under flowing water conditions is illustrated in Table 2. Growth was significantly reduced by treatment (Table 3).

Although herbicide concentration was not consistently maintained under flowing water conditions by the MOE/2,4-D GMA CRHF, phytotoxic levels were maintained.

Variability in herbicide concentration was due in part to inadequacies in the flow system and possibly to erratic release of herbicide from the polymer, or from loss of CRHF when jars overflowed.

A second trial is currently in progress utilizing a clay granule formulation of the 2,4-D copolymer. The flow system was modified to reduce variability due to flow rate, and results of these evaluations will be reported later.

Dichlobenil

Another CR formulation we have evaluated in our laboratory is a formulation of dichlobenil in beeswax. This also was developed in

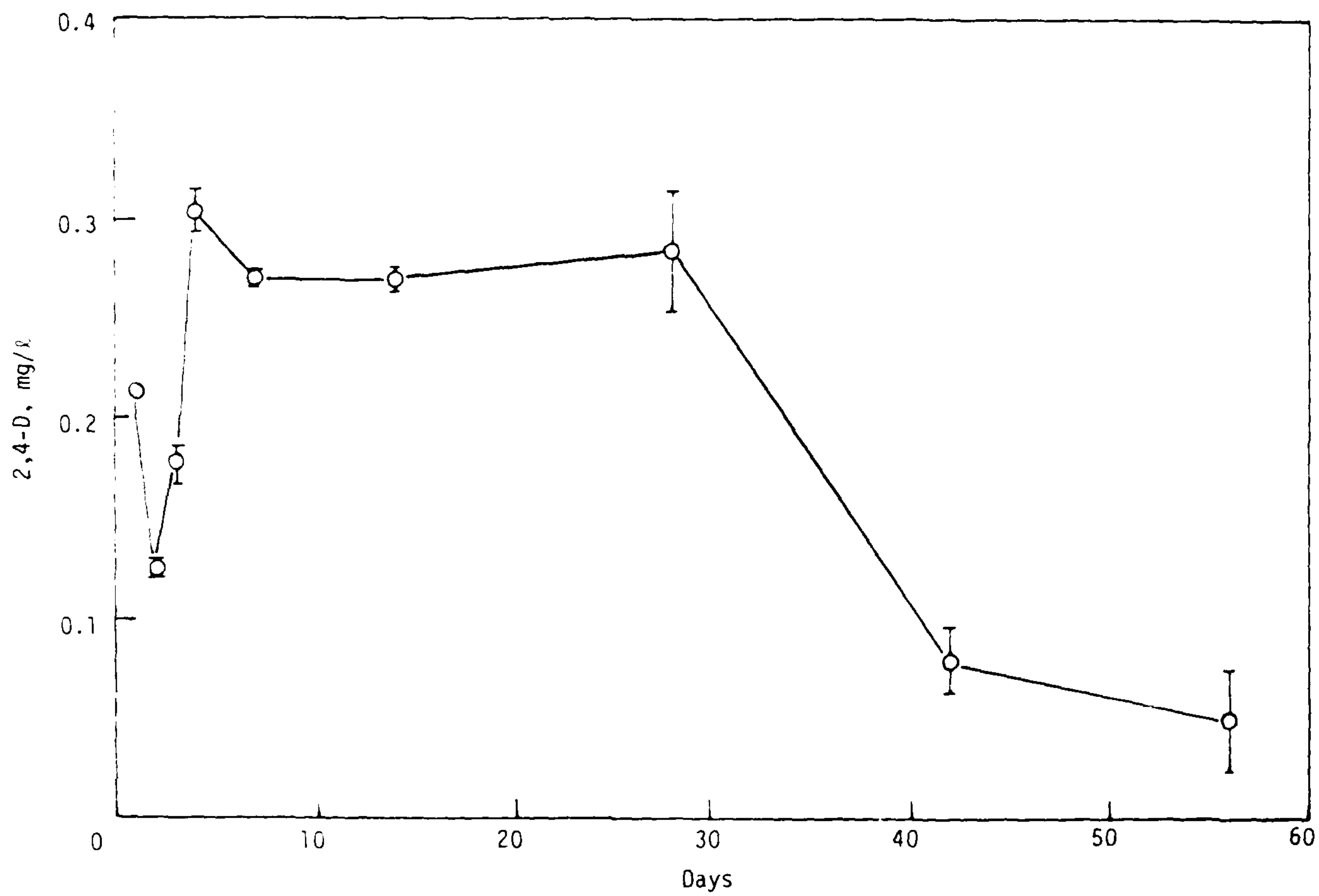

Figure 8. Release of 2,4-D from MOE/GMA copolymer into flowing natural water

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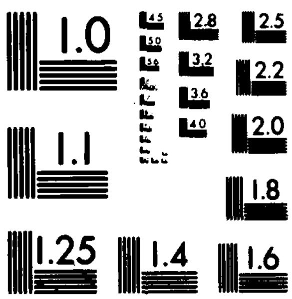

MICROCOPY RESOLUTION TEST CHART
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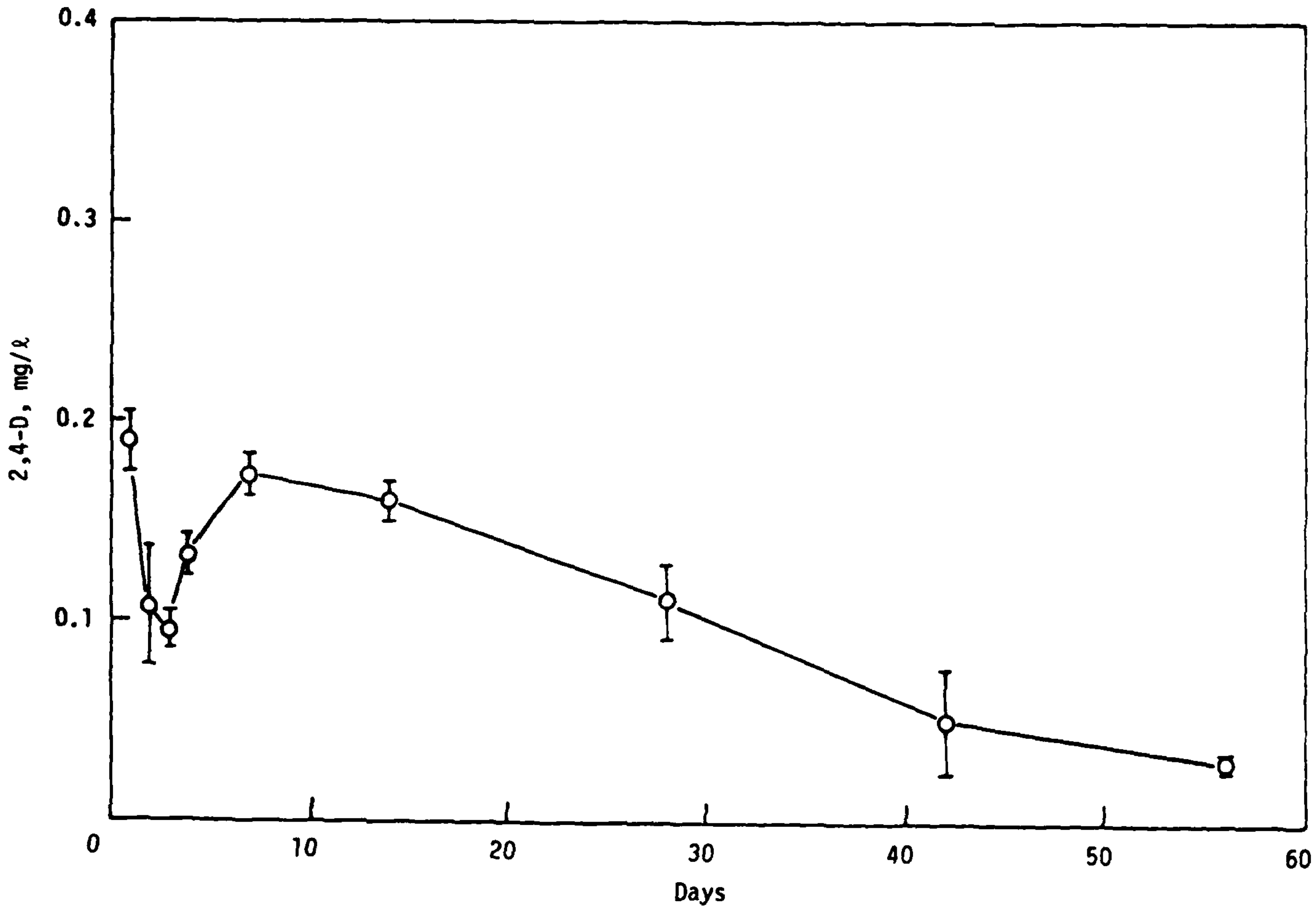

Figure 9. *Influence of soil* and watermilfoil on 2,4-D concentration in flowing water as released from MOE 2,4-D/GMA CRHF

Dr. Harris' laboratory. We are in the process of determining release rates from the pellet and degradation of the herbicide in natural water. Some preliminary findings on release rates are described below.

Dichlobenil appeared to be slowly released from the beeswax pellet as indicated by the gradual increase in concentration with time (Table 4). A plot of the release rate data revealed a decreasing rate of release with time (Figure 10). The theoretical (designed) release rate was expected to be 0.2 mg/g CRHF/day; however, the measured rate was four times greater than expected after the first day and decreased to approximately 74 percent of the expected release rate after 28 days. To account for possible rapid release of the chemical at or near the pellet surface, the data were corrected by subtracting the amount released the first day that exceeded the expected amount. Inspection of these data indicated that release rate was: greater than expected the first 7 days; approximately as expected after 2 weeks; and less than expected beyond 10 weeks.

These preliminary data indicate that release of dichlobenil from the beeswax CRHF is not constant but tended to decrease with time. Microscopic examination of the pellets reveals an accumulation of a crystalline substance at the surface which may account for the initially high concentration of the herbicide in the water.

Future research

Plans for next year include additional laboratory evaluations as well as evaluation of the MOE/GMA CRHF in outside aquaria.

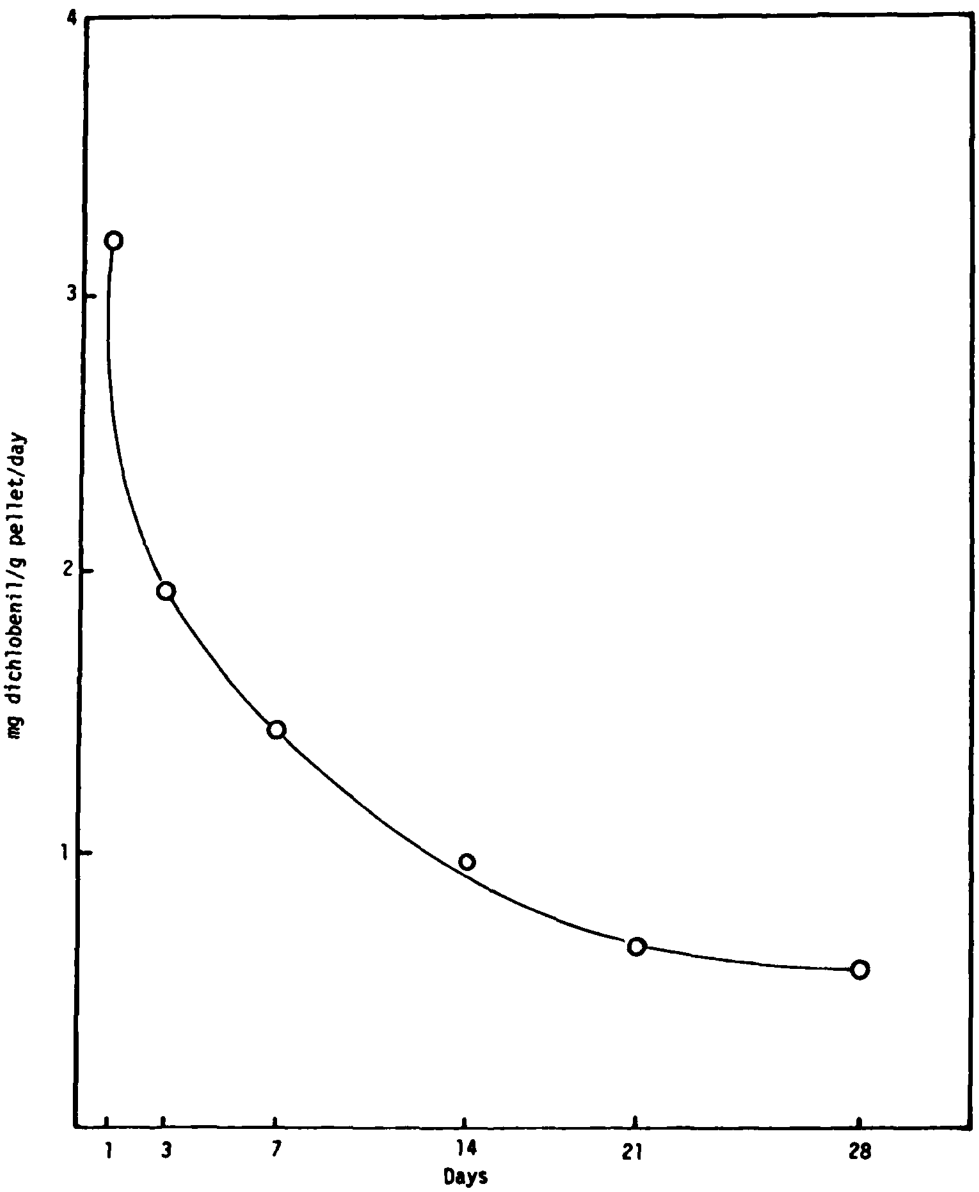

Figure 10. Release of dichlobenil from beeswax pellets into static reconstituted water

Table 1

Degradation of Various Concentrations of 2,4-D (μg/ℓ Measured)*
in Static Natural Water in the Laboratory

Applied 2,4-D μg/ℓ		Days Posttreatment 0	1	2	7	14	28	42	70
10	A	7	10	11	11	11	9	8	8
	B	6	11	10	13	8	7	8	5
	Ave	7	11	11	12	10	8	8	6
25	A	23	26	22	26	21	22	19	19
	B	19	22	23	27	21	18	18	20
	Ave	21	24	22	26	19	20	18	19
50	A	33	44	40	51	45	11	ND**	ND
	B	26	47	43	54	43	43	42	43
	Ave	30	46	42	53	44	27	21	21
100	A	89	107	84	102	83	85	86	76
	B	89	100	78	105	88	89	73	61
	Ave	89	104	81	104	86	87	80	63
250	A	235	234	208	261	232	228	228	212
	B	158	205	205	257	195	74	8	ND
	Ave	196	220	206	259	214	142	118	106
Control									
	A	ND	ND	ND	ND	ND	ND	ND	ND
	B	ND	ND	ND	ND	ND	ND	ND	ND
	Ave	ND	ND	ND	ND	ND	ND	ND	ND

* Average of three determinations per replicate.
** Not detected.

Table 2

Phytotoxic Response (Average Percent Injury)*
of *M. spicatum* to Controlled Release
of 2,4-D Into Flowing Ambient Water

	Weeks Posttreatment		
	2	4	8
Treated	45	76	64
CV**	16%	14%	61%
Control	18	23	19
CV**	86%	53%	70%

* Mean of three replicates.
** Coefficient of variation.

Table 3

Effect of 2,4-D Released from MOE/GMA CRHF on *M. spicatum*
Growth After 8 Weeks in Flowing Water

	Stems		Roots
	Fresh Weight, g	Length, cm	Fresh Weight, g
Treated	0.36	9.5	0.56
Control	3.40	36.8	1.32
t-test	3.73*	4.18*	4.8**

Note: t @ 0.01 = 3.7, t @ 0.005 = 4.3.
* Significant
** Very significant.

Table 4

Release of Dichlobenil from Beeswax Pellets into Static Reconstituted Water

Days Posttreatment						
1	3	7	14	21	28	56
			Concentration, mg/ℓ			
0.22	0.40	0.71	0.91	0.97	1.14	
			Total mg Released			
0.8	1.4	2.5	3.2	3.4	4.0	
			Expected mg Released			
0.2	0.6	1.4	2.7	4.1	5.4	10.9
			Corrected mg Released			
0.2	0.8	1.9	2.6	2.8	3.4	

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Study of a Naturally Occurring Hydrilla Inhibitor

by

Dean F. Martin* and Patricia M. Dooris*

Introduction

It seems evident that alternative measures designed to control hydrilla are needed that do not bring about drastic environmental changes. It is encouraging to note that certain lakes do not support hydrilla as well as others (Martin, Doig, and Millard 1971; Martin, Victor, and Dooris 1976; Barko and Smart 1980). In lakes that fall into this category, other macrophytes appear to grow quite well (personal observations 1972-1980); thus, factor(s) discouraging hydrilla do not discourage all other submersed plants.

The lake that we have studied most intensely in Hillsborough County, Florida (Lake Starvation), is dark colored; organic material from adjacent stands of baldcypress (*Taxodium disticium*) comprises a significant fraction of the lake sediment. A second lake that we have studied near Tampa (White Trout Lake) also had been devoid of hydrilla, despite its abundance in nearby Lake Carroll. White Trout Lake is less intensely colored, though, a considerable amount of the sediment in certain sections is derived from cypress sawdust. Evidently at one time a sawmill was located near the lake.

We believe that an examination of the relationship between hydrilla growth and the sediments in these and other lakes could prove useful in explaining how some lakes appear "immune" to hydrilla. An explanation of this phenomenon would be useful for at least three reasons: (1) in describing those factors that control the distribution of submersed plants; (2) by defining those conditions that might warrant reduced monitoring for the management of submersed aquatics; and (3) by possibly isolating, characterizing, and identifying inhibitory substances from lake sediments that could be developed for use in a program for hydrilla containment through the use of naturally occurring substances.

Experimental

Preparation of lake sediment extracts

Sediments from Lake Starvation were collected and returned to the

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laboratory. Extracts of each sediment sample were prepared according to the following scheme. Fresh wet sediment (300 g) was subjected to autoclaving (120°C, 20 psi, 20 min) in the presence of 600 ml of deionized, distilled water. The resulting dark-colored fluid was separated from the sediment by filtration, first through Whatman No. 1 filters, followed by Millipore 8-μ filters. An aliquot of the filtrates (Fraction A) was reserved and subjected to no further filtration. The remaining filtrate was subjected to ultrafiltration and analysis.

Ultrafiltration

An Amicon apparatus operated at 40 psi nitrogen and the following filters were used: 10 μm, 2 μm, and 0.05 μm which have nominal molecular weight cutoff points at 10,000, 2,000, and 500, respectively. A portion of each filtrate was reserved and the <10,000 material was referred to as Fraction B; the <2,000 as Fraction C; and <500 as Fraction D. The extracts were stored in tightly closed glass bottles at -30°C.

Analysis of sediment

Representative samples were obtained by sectioning and comingling. Water was determined by loss of weight following drying at 110 ± 5°C for 18 days. Organic carbon was determined as weight loss after heating in a muffle furnace 16 hr at 375°C (Ball 1964).

Growth experiments with hydrilla

The protocol described in Dooris and Martin (1980) was followed: studies were conducted using stoppered, inverted 500-ml Erlenmeyer flasks. Control vessels contained a known length (75 mm) and weight of apical plant material in Hoagland's solution (Steward and Elliston 1973). Test vessels contained the above in addition to 0.8 ml of an extract fraction. Growth estimates were based upon changes in wet weight (as measured to ± 0.01 g) during a 7-day period. Consistent agreement had been obtained previously between wet weight and dry weight (Dooris and Martin 1980).

Results and Discussion

Effects of extraction upon the growth of hydrilla

The advantage of using an autoclave appears to be threefold: better yield of organic material, active material obtained, and any organisms present in the sediment destroyed.

Fairly consistent results were noted when a sediment from a given site was extracted. For example, Dooris and Martin (1980) reported that Fraction A had an organic carbon content of 480 ppm, and the present study using sediment collected at a different time yielded six extracts with a mean organic carbon content of 435 ± 85 ppm.

In contrast, room temperature extraction was much less efficient.

At 30°C, extraction for 48 hr under nitrogen gave a solution containing less than 50 ppm organic carbon. At 35°C, extraction for 2 weeks in a gyrotary shaker gave a solution containing 240 ppm organic carbon; extraction for 4 weeks in a shaker bath did not produce a higher concentration.

Under the conditions used (120°C, 20 psi, 20 min), usually about 9.33 percent of the total organic matter was extracted.

The sediment in Lake Starvation is fairly high in organic content, about 26 percent. For comparison, Sawgrass Lake in Pinellas County, Florida, has apparent organic carbon of 30 percent.

In the presence of Fractions A and B from Lake Starvation or Fraction A from White Trout Lake, the growth of hydrilla after 7 days was significantly less than that observed in the control systems. When control plants showed an average increase of 20 percent, the test plants showed decreases or only slight increases in weight. The dark-green color and dense-leaved appearance of the control plants may be contrasted with the yellowish brown and partially defoliated plants grown in the presence of extract Fractions A and B (Fractions C and D had no significant effect on the growth).

General separation

The crude extract was fractionated using ultrafiltration into nominal molecular-weight fractions. From the parent fraction, additional fractions (three) may be obtained using a series of filters. Fraction B_1 (i.e., the material that passed through the <10,000-μm filter, but not the <2,000-μm filter) had maximum activity with respect to inhibition of hydrilla growth. Fraction C_1 and D_1 either had much less inhibitory activity or did not differ significantly from control experiments.

In addition, a further separation was made for purposes of analyzing the samples by means of high performance liquid chromatography (HPLC). The fractionated sample (B_1) was absorbed onto a short (13 × 7 mm) methanol-activated, C-18, reverse-phase liquid chromatography column (SEP-PAK), and the eluant was collected. In addition, the methanal-soluble fraction was also collected. Both were subjected to fractionation.

Fractionation of hydrilla-
inhibiting fraction by HPLC

Initial separation by SEP-PAK cartridges was necessary because some material in the hydrilla-inhibiting fraction was strongly absorbed on the packing used in reverse-phase chromatography. Thus, a preliminary separation removed the very strongly absorbing material, but it removed only a relatively small portion of the total organic content (estimated to be less than 10 percent, based upon analysis of organic carbon content before and after absorption and elution).

A number of subfractions can be recognized, based upon the information obtained from the chromatograms. Quite possibly over a dozen

fractions could be recognized. It must be emphasized that these are the materials that absorb at 254 nm (fixed wavelength detector).

Structural information on the inhibitor

A better estimate of molecular weight will come from analysis of purified components of the active fraction. The components, purified by HPLC, will be subjected to mass spectrometry. Again, limitations become apparent: most mass spectrometers do not accommodate molecules with molecular weights in excess of 600. But a sample has been sent to the Mid-Atlantic Mass Spectrometry Laboratory in the hope that this National Science Foundation supported laboratory would be able to obtain a satisfactory analysis.

In addition, the purified components have been subjected to mass spectrometry using an instrument that analyzes samples in the 0- to 650-molecular weight region. At this time, the results of this study are incomplete.

Other structural information comes from the infrared spectra which have strong absorbances at 3600-3300 cm^{-1}, 3100-3300 cm^{-1}, 1650-1500 cm^{-1}, and 1300-1080 cm^{-1}, all of which are consistent with the existence of aromatic, possibly phenolic moieties.

In addition, it was found that the inhibitory fraction was associated with the anionic portion of the active fraction (cf Dooris and Martin 1980). When the active fraction, B_1, was passed over a cation exchange resin (Chelex-100), no loss in activity occurred. When the material was absorbed on an anion exchange column, the eluant had no color and no activity.

Additional structural information must await mass spectrometry analysis and other, more detailed studies.

Conclusions

The following conclusions can be drawn from this study:

a. It has been demonstrated that a material that inhibits the growth of *Hydrilla verticillata* can be obtained from the aqueous extracts of Lake Starvation sediment.

b. Active material can be obtained by aqueous extraction of the sediment at room temperature or near room temperature.

c. A much better yield of material is obtained, however, by extraction of the sediment in an autoclave.

d. The inhibiting character of the extracts does not appear to be the result of manganese toxicity. In addition, nickel and cadmium levels in the extracts were below reasonable detection limits.

e. The iron levels in the extracts did not appear to be sufficient to account for inhibition of hydrilla growth.

f. It was possible to separate the active fraction by means of ultrafiltration using sized membrane filters. The active fraction obtained from ultrafiltration can be further fractionated into components, some of which are active against a test organism (*Chlamydomonas reinhardii*).

g. It seems evident that the inability of hydrilla to thrive in Lake Starvation in part is the result of naturally occurring materials that are extracted from the sediments, though the mechanism of production of these materials is presently unknown.

h. Commercially available humic acid can also be extracted to produce a hydrilla-inhibiting fraction.

i. Additional structural information needs to be obtained from mass spectrometry and other studies of the purified components of the active fraction.

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Acknowledgments

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CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

New Controlled-Release Formulations

by

C. Himel,* T. Quick,** L. Boswell,** and N. Cardarelli**

Introduction

Aquatic herbicides were monolithically incorporated in elastomers in 1969 under the auspices of the U. S. Army Corps of Engineers (Bille, Mansdorf, and Cardarelli 1970). This was an extension of earlier work involving the development of controlled-release antifouling agents and molluscicides (Cardarelli and Caprette 1969; Cardarelli and Neff 1972). Field and laboratory testing of controlled-release formulation of the butoxyethanol ester of 2,4-dichlorophenoxyacetic acid indicated efficacy against waterhyacinth and Eurasian watermilfoil (Cardarelli 1976; Thompson 1974). In a later Army Corps of Engineers project it was shown that the CT relationship, Habers principle, was inoperative at ultra low herbicide dosages and the "chronicity phenomenon" was discovered (Quinn, Cardarelli, and Gangstad 1972). Essentially, it was demonstrated that various aquatic plants will succumb to herbicide dosages as low as 0.001 ppm/day as long as the exposure time was prolonged to three or more weeks (Quinn, Cardarelli, and Gangstad 1977). This is not observed with all aquatic plant-herbicide combinations, but is observed with a significant number. The effect is possibly due to the herbicide concentration being below the threshold limit that triggers protective responses in the target plant (Cardarelli 1975).

Background

It has long been recognized that pesticides are soluble to varying limits in select elastomers. Upon incorporation in elastomeric polymers and immersion in water, the agent slowly migrates, under solution pressure, to a depleting interface. The diffusion-dissolution process has been elucidated in Cardarelli (1976). Since pesticidal chemicals are not soluble in plastic matrices, it was believed that no operable release mechanism was possible. However, in 1973, it was discovered that an elastomer insoluble water, soluble agent, copper sulfate, would release from an elastomer if a coleachant was incorporated (Walker and Cardarelli 1977).

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Insecticide work began with thermoplastic matrices in 1975. It was discovered that organotins and organophosphate materials could be released at a slow efficacious rate from polyethylene and other thermoplastic polymers via a leaching type system (Cardarelli 1978; Himel, Quick, and Cardarelli 1979). Two principles were involved: creation of the proper free volume within the matrix using polymer alloys consisting of two such polymers having widely divergent melt indices; and the incorporation of a porosity-inducing agent or "porosigen" (Cardarelli 1979, 1980). The porosigen must be water soluble and thus will slowly leach out of the plastic dispenser creating a porosity network. This allows egress of water, water contact of the agent, agent salvation, and passage through the interface to the external water course. Release over a 3- to 7-year period has been achieved with tributyltin fluoride, temephos, and other insect larvicides.

Thermoplastic Dispensers

Plastics can be formed into a large number of geometries. By adjusting the density through the use of additives, sinking and floating pellets or granules have been produced. In order to overcome silt-over problems, anchored coordinated strands have been commercially produced and used in catch basins for mosquito larviciding purposes (ECOPRO™1707, Environmental Chemicals Inc.) (Himel, Quick, and Cardarelli 1979). Similarly anchored floating chips of the same material have been used in potable water reservoirs under World Health Organization projects. Recently, a bimodal pellet has been produced that floats on mud and rises as silt is deposited so that the dispensing surface is always in contact with water. Figure 1 illustrates various designs of dispensing systems. All are in pilot plant production as insecticide or molluscicide carriers.

Formulations

A number of herbicidal agents were monolithically dispersed in thermoplastic matrices. The general scheme was keyed to the evaluation of various porosigens.

Test Methods

Elodea canadensis, common elodea, specimens were planted in 100 g of a 50/50 potting soil/sand mix in a 6-oz styrofoam cup. Three plants were used per replicate with four replicates per run. Cups were sunk in 3 ℓ of cistern water in a 4-ℓ widemouth transparent jar. In the indoor tests, jars were placed under standard Gro-lux lights on a 14/10 hour day/night cycle. Jar mouths were sealed with plastic wrap to minimize water loss through evaporation.

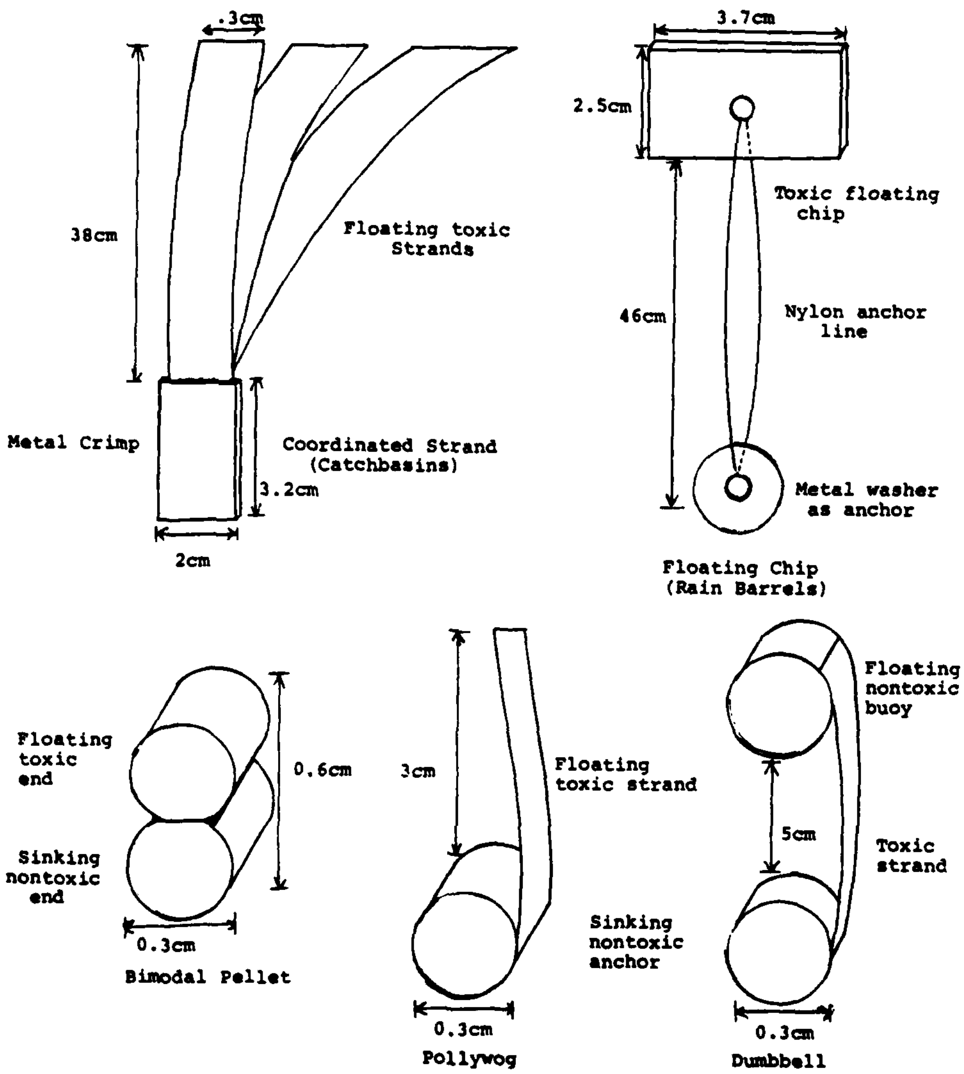

Figure 1. Various dispenser geometries

Myriophyllum spicatum, Eurasian watermilfoil, plants were similarly planted, except that the test jars were set up outdoors during June 1980, at a farmsite in Peninsula, Ohio. Plants were in direct sunlight during the morning hours but shaded from the afternoon sun.

Eichhornia crassipes, waterhyacinth, plants were also tested outdoors using three small plants floating in 3 ℓ of water in a 4-ℓ bucket-type container. As a nutrient base 100 g of potting soil was added to each container. Each test consisted of three relicates plus one control per formulation dosage.

Pistia stratiotes, waterlettuce, was similarly tested.

Salvinia was tested indoors by covering the water surface in 4-ℓ widemouth jars containing 1 ℓ of cistern water, with 50 g of potting soil added. Gro-lux lighting was used, and the 14/10 hour day/night cycle was automatically maintained. Plastic wrap with punched ventilation holes was placed over the mouth of each test container.

Lemna minor, duckweed, was tested in a similar manner.

Cabomba caroliniana and *Vallisneria americana* were potted and tested in a method similar to that of *Elodea*.

All plants were conditioned for 1 to 2 weeks prior to the test and those showing any manifestation of poor health were replaced.

On the intial test day, 0.3- by 0.2-cm pellets were added at the selected dosage level. Plants were observed daily for toxic effects. The mortality criterion used varied from specie to specie, but was visual observation of the degree of browning, loss of foliage, or decay observed. A 0- to 10-point scale was used, with 10 being a healthy, visually unaffected plant and 0 indicating mortality.

Bioassay Results

Phytotoxicity is indicated in Table 1 for the various controlled-release herbicide formulations. Generally, observations were made for 6 weeks. Results are summarized as a percent mortality based upon an averaging of the replicates, reported herein at 5-day intervals. The dosage given is for the total active agent in the pellet, i.e., the water concentration that would ensue if all the toxic agent were released at once. Actual agent emission occurs for 12 or more months (with exceptions) so that a given 10-ppm dosage must be divided by the total release time to get a dose per day. For instance, if the given formulation, applied at 10-ppm active ingredient, were released over 365 days at a constant and continuous rate, the daily emission dose would be 0.03 ppm/day.

Results

Test data from the selected bioassays reported herein (and the

dated compendium of work too large to conveniently report herein) indicate that: (1) herbicidal agents can be incorporated in inexpensive thermoplastic matrices, and (2) porosigenic coleachants release at biologically efficacious rates over an extended period of time. Herbicidal agents examined in this program included not only Diquat, Diuron, Fenac, and Bromacil, but also 2,4-D acid, 2,4-D butoxyethanol ester, 2,4-D butylester, 2,4-D dimethylamine, 2,4-D oleylamine, Simazine, Atrazine, and Dichlobenil. A total of 120 formulations were evaluated; these results will be published in due course. Relatively little work has been done in the determination of release rates. The superior performance of Diquat material has prompted a chemical analysis of Diquat loss from various formulations over a period of time. Figure 2 illustrates loss curves. Extrapolation of data indicates a release half-life for the various floating pellet formulations:

Materials	Diquat Release Half-Life
2503A	40 days
2503B	61 days
2503C	160 days
2503D	35 days
2503H	31 days
2503J	19 days

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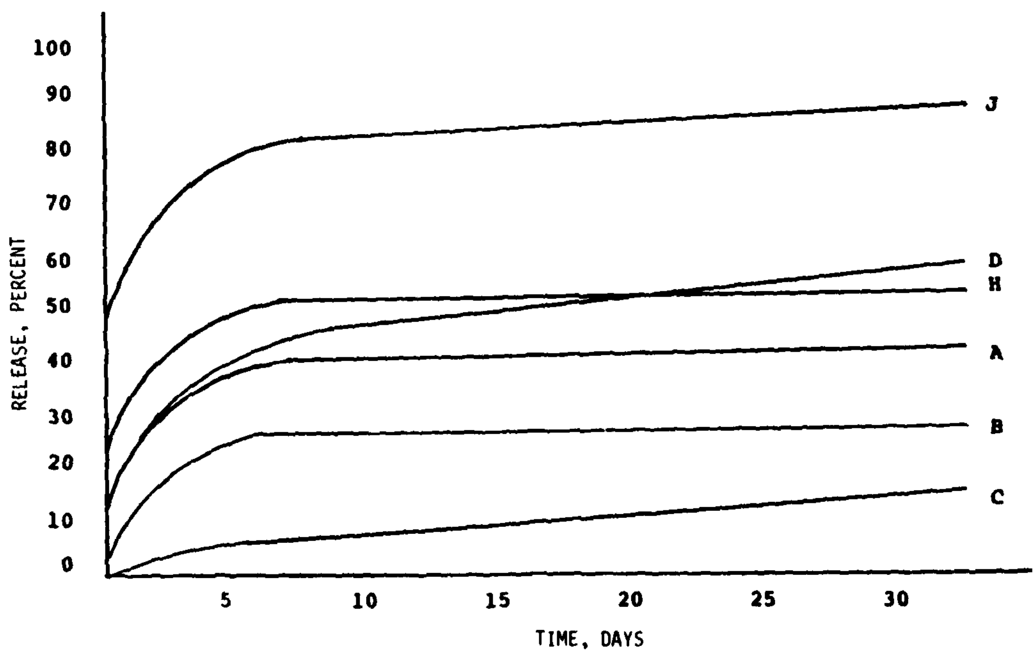

Figure 2. Release rates for 2503 series Diquat

Himel, R., Quick, T., and Cardarelli, N. F. 1979. "Field and Laboratory Evaluations of Controlled Release Temephos and Tributyltin Fluoride Mosquito Larvicides," Proc. 6th International Symp. Controlled Release of Bioactive Materials, (Abst. IV-32 to IV-36) New Orleans, La.

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Table 1

Phytotoxicity of Controlled-Release Formulations

Formulation No.	Agent	Dosage ppm	Accumulative Percent Mortality, days 5	10	15	20	25	30	35	40
			Elodea canadensis Bioassay							
2504D	Fenac	10	5	7	20	37	55	73	83	95
		1	0	0	5	7	20	37	53	60
2507A	Bromacil	10	0	5	7	10	30	63	77	100
		1	0	5	5	25	43	60	70	87
2507C	Bromacil	10	0	0	5	13	30	50	55	75
		1	0	0	7	10	15	35	50	55
2507D	Bromacil	10	0	3	13	25	37	60	75	87
		1	0	3	7	13	23	55	67	85
2507F	Bromacil	10	0	0	0	5	7	30	50	60
		1	0	3	7	13	15	35	43	47
2507G	Bromacil	10	0	10	23	43	73	85	90	100
		1	0	7	7	20	33	65	67	93
2507H	Bromacil	10	0	7	15	20	45	85	95	100
		1	0	7	3	10	17	37	45	53
Controls		--	1	2	2	2	5	7	7	7
			Myriophyllum spicatum Bioassay							
2501D	Diuron	10	17	30	42	75	95	100	--	--
		1	5	10	20	33	53	85	100	--
2501G	Diuron	10	25	60	85	100	--	--	--	--
		1	0	5	10	13	37	75	100	--
2501H	Diuron	10	17	65	73	97	100	--	--	--
		1	5	15	17	35	45	45	--	--
2503A	Diquat	10	47	73	77	83	85	100	--	--
		1	40	50	65	67	73	90	100	--
2503D	Diquat	10	37	67	83	90	93	100	--	--
		1	17	33	60	65	73	85	100	--
2503H	Diquat	10	65	80	87	92	97	100	--	--
		1	13	35	83	93	100	--	--	--

(Continued)

(Sheet 1 of 5)

Table 1 (Continued)

Formulation No.	Agent	Dosage ppm	Accumulative Percent Mortality, days 5	10	15	20	25	30	35	40
			Myriophyllum spicatum Bioassay (Continued)							
2503J	Diquat	10	43	67	83	90	100	--	--	--
		1	20	33	50	80	97	100	--	--
Controls		3	3	3	5	7	7	7	9	--
2504D	Fenac	10	5	37	53	73	75	75	--	--
		1	3	13	23	27	27	30	--	--
2507A	Bromacil	10	10	15	53	95	100	--	--	--
		1	3	7	27	53	60	60	--	--
2507D	Bromacil	10	0	3	17	37	77	97	100	--
		1	5	12	12	15	15	27	--	--
2507F	Bromacil	10	3	17	25	82	100	--	--	--
		1	10	17	25	40	40	--	--	--
2507G	Bromacil	10	7	67	97	100	--	--	--	--
		1	0	0	0	5	10	15	--	--
Controls		--	0	0	0	2	3	4	6	--
			Eichhornia crassipes Bioassay							
2501D	Diuron	10	7	13	43	80	100	--	--	--
		1	0	0	3	3	10	10	--	--
2501G	Diuron	10	3	20	73	100	--	--	--	--
		1	7	7	17	20	20	20	20	--
2501H	Diuron	10	7	40	80	100	--	--	--	--
		1	3	3	3	3	3	3	3	--
2503A	Diquat	10	7	37	77	90	100	--	--	--
		1	7	17	30	37	60	73	--	--
2503B	Diquat	10	0	33	77	90	100	--	--	--
		1	0	3	3	3	7	13	17	--
2503C	Diquat	10	7	43	83	93	97	100	--	--
		1	7	7	13	13	13	13	17	--
2503D	Diquat	10	7	50	93	100	--	--	--	--
		1	0	0	7	13	20	33	--	--
2503H	Diquat	10	23	80	100	--	--	--	--	--
		1	0	0	23	20	37	50	--	--

(Continued)

(Sheet 2 of 5)

Table 1 (Continued)

Formulation No.	Agent	Dosage ppm	Accumulative Percent Mortality, days 5	10	15	20	25	30	35	40
			Eichhornia crassipes Bioassay (Continued)							
2503J	Diquat	10	10	70	93	100	--	--	--	--
		1	3	10	27	30	33	33	--	--
2504D	Fenac	10	10	33	60	87	100	--	--	--
		1	3	7	7	17	17	17	--	--
2507G	Bromacil	10	10	90	100	--	--	--	--	--
		1	3	63	67	70	70	70	--	--
2507H	Bromacil	10	20	100	--	--	--	--	--	--
		1	3	67	70	70	80	--	--	--
Controls		--	2	6	7	7	8	8	9	--
			Pistia stratiotes Bioassay							
2501D	Diuron	10	13	57	87	100	--	--	--	--
		1	7	20	33	37	57	63	--	--
2501G	Diuron	10	10	73	97	100	--	--	--	--
		1	10	30	57	80	90	100	--	--
2501H	Diuron	10	10	77	97	100	--	--	--	--
		1	13	53	80	93	100	--	--	--
2503A	Diquat	10	37	80	90	100	--	--	--	--
		1	3	3	3	3	7	17	--	--
2503B	Diquat	10	97	100	--	--	--	--	--	--
		1	3	7	13	17	23	30	--	--
2503C	Diquat	10	37	60	77	97	100	--	--	--
		1	7	7	7	10	10	10	--	--
2503D	Diquat	10	97	100	--	--	--	--	--	--
		1	7	13	13	20	23	23	--	--
2503H	Diquat	10	100	--	--	--	--	--	--	--
		1	3	3	13	17	27	33	--	--
2503J	Diquat	10	67	80	90	100	--	--	--	--
		1	0	0	10	17	20	30	--	--
2507G	Bromacil	10	20	100	--	--	--	--	--	--
		1	13	80	93	97	100	--	--	--

(Continued)

(Sheet 3 of 5)

Table 1 (Continued)

Formulation No.	Agent	Dosage ppm	Accumulative Percent Mortality, days 5	10	15	20	25	30	35	40
			***Pistia stratiotes* Bioassay (Continued)**							
2507H	Bromacil	10	23	100	--	--	--	--	--	--
		1	13	97	100	--	--	--	--	--
Controls		--	0	2	3	4	5	10	--	--
			***Salvinia* Bioassay**							
2501H	Diuron	10	3	23	60	83	97	100	--	--
		1	0	5	20	30	42	56	--	--
2503C	Diquat	10	3	55	100	--	--	--	--	--
		1	5	53	95	97	100	--	--	--
2503H	Diquat	10	20	90	100	--	--	--	--	--
		1	5	53	65	67	67	--	--	--
2503J	Diquat	10	7	65	100	--	--	--	--	--
		1	0	35	60	62	67	--	--	--
2507G	Bromacil	10	5	30	75	87	100	--	--	--
		1	12	47	82	90	95	100	--	--
2507G	Bromacil	10	10	50	85	95	100	--	--	--
		1	2	12	32	75	95	100	--	--
Controls		--	0	0	2	5	8	8	--	--
			***Lemna minor* Bioassay**							
2501D	Diuron	10	0	30	67	87	100	--	--	--
		1	0	17	30	50	87	100	--	--
2501G	Diuron	10	5	37	67	93	100	--	--	--
		1	0	10	30	45	75	100	--	--
2501H	Diuron	10	10	35	65	87	100	--	--	--
		1	2	20	35	73	85	100	--	--
2503A	Diquat	10	52	100	--	--	--	--	--	--
		1	10	55	60	67	100	--	--	--
2503B	Diquat	10	5	92	100	--	--	--	--	--
		1	2	50	90	97	100	--	--	--
2503C	Diquat	10	20	100	--	--	--	--	--	--
		1	10	100	--	--	--	--	--	--

(Continued)

(Sheet 4 of 5)

Table 1 (Concluded)

Formulation No.	Agent	Dosage ppm	Accumulative Percent Mortality, days 5	10	15	20	25	30	35	40
			Lemna minor Bioassay (Continued)							
2503D	Diquat	10	20	100	--	--	--	--	--	--
		1	7	97	100	--	--	--	--	--
2503H	Diquat	10	20	97	100	--	--	--	--	--
		1	10	77	100	--	--	--	--	--
2503J	Diquat	10	15	100	--	--	--	--	--	--
		1	12	100	--	--	--	--	--	--
2507G	Bromacil	10	0	30	75	83	100	--	--	--
		1	0	22	52	75	95	100	--	--
2507H	Bromacil	10	0	17	70	87	100	--	--	--
		1	0	12	30	65	93	100	--	--
Controls		--	0	4	6	10	21	25	--	--
			Cabomba caroliniana Bioassay							
2504D	Fenac	10	17	17	40	47	83	--	--	--
		1	10	10	30	35	37	--	--	--
2507H	Diquat	10	5	5	12	30	80	94	--	--
		1	22	30	43	63	83	87	--	--

(Sheet 5 of 5)

LARGE-SCALE OPERATIONS MANAGEMENT TESTS

Use of White Amur for Control of Hydrilla in Lake Conway in the Jacksonville District

by

Eugene G. Buglewicz* and Andrew C. Miller*

For the past 6 years, the Large-Scale Operations Management Test (LSOMT) at Lake Conway has been presented at this operations review meeting as a planned or ongoing project. As with all research, the end must come, and for the intensive field effort on Lake Conway designed to describe the use of the white amur to control hydrilla and document the environmental consequences of its introduction, the end has arrived.

Major funding support for the Lake Conway project is provided by the Jacksonville District with direct allotted support from the Office, Chief of Engineers. The many meetings, man-hours, and money provided by the sponsors are indicative of the potential importance the results of such a test may have on effective control of nuisance aquatic plants, not only in Florida but throughout the United States.

As of 30 September 1980, the intensive fieldwork on Lake Conway ceased, and both the researchers working in the field and personnel at the U. S. Army Engineer Waterways Experiment Station (WES) are preparing the final reports documenting the aquatic plants, fish, plankton, benthos, water quality, and herpetofaunal populations in the study area. These reports, however, are not the only final product of the 4 years of investigation. Based on the results of the field studies, a manual for the use of the white amur to control hydrilla will be produced and distributed to the field. Our schedule calls for the manual to be made available in 1982, and will integrate the LSOMT results and corollary studies conducted by the Aquatic Plant Control Research Program (APCRP) and other literature and research performed on this most controversial fish.

A low level field effort will continue during FY 81 on Lake Conway to provide information on distribution and biomass of aquatic plants and fish and herpetological population information. Development is continuing on the second-generation stocking rate model at WES to incorporate the results of current research on both hydrilla and the white amur.

Ahead of us lies the most difficult of all tasks, consolidating the Lake Conway data and presenting it in a form usable by Corps of Engineer field offices. You will find the information provided by the Lake Conway

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

investigators both interesting and informative; this information will allow you to appreciate the complexity of this field project and the requirement for careful integration and analysis of environmental information dealing with the white amur.

LARGE-SCALE OPERATIONS MANAGEMENT TEST

Aquatic Macrophytes

by

Jeffrey D. Schardt* and Larry E. Nall*

Introduction

The Florida Department of Natural Resources, under contract to WES, has been conducting aquatic plant studies in Lake Conway since October 1976. By September 1980, 48 consecutive months of data had been collected. A detailed report of results through the fourth study year is in preparation. This paper is a brief update of major trends after the fourth study year.

Methodology

Four types of vegetation sampling are employed in Lake Conway. The first type uses a hydraulic sampling device which is lowered from a 25-ft pontoon boat (Figure 1). This barge and sampling device were designed specifically for use in Lake Conway. Each month the device collects measured samples at 100-m intervals along 18 transects throughout the lake system (Figure 2). Transect samples yield standing crop and percent frequency data.

Another major type of sampling is carried out by scuba divers who examine 16 1.0-ha underwater plots each month (Figure 3). Divers survey the area to determine percent frequency of each species and fixed heights at predetermined points within the plot. A 0.25-m^2 plant sample is removed for stem density, wet weight, and plant height determinations.

Beginning in September 1980, random sampling procedures will be conducted quarterly and combined with vegetation coverage data obtained from fathometer transects for a better understanding of percent frequency and standing crop in areas not sampled by transects and plots.

Results

Feeding preference

A list of aquatic plant species in approximate order of preference by the white amur is presented in Table 1. The four major species

* Florida Department of Natural Resources, Bureau of Aquatic Plant Research and Control, Tallahassee, Florida.

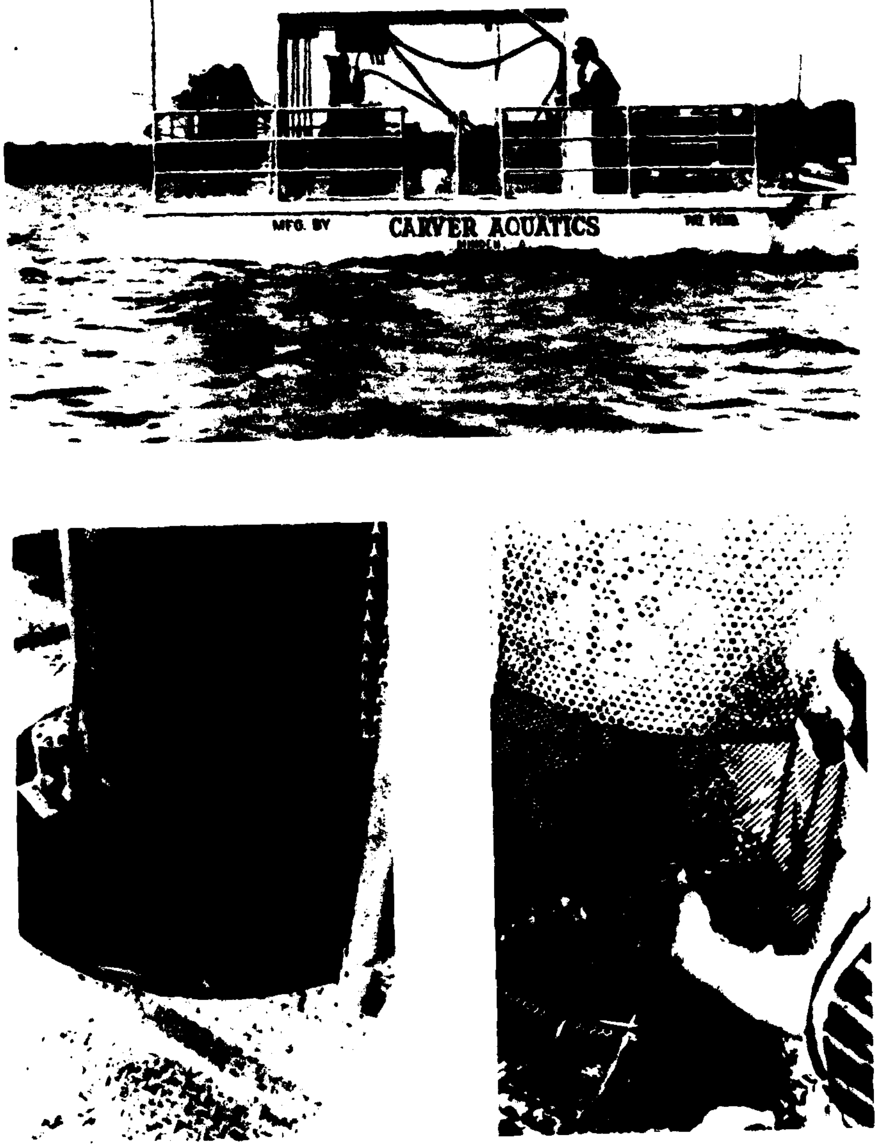


Figure 1. Barge and aquatic plant sampling device

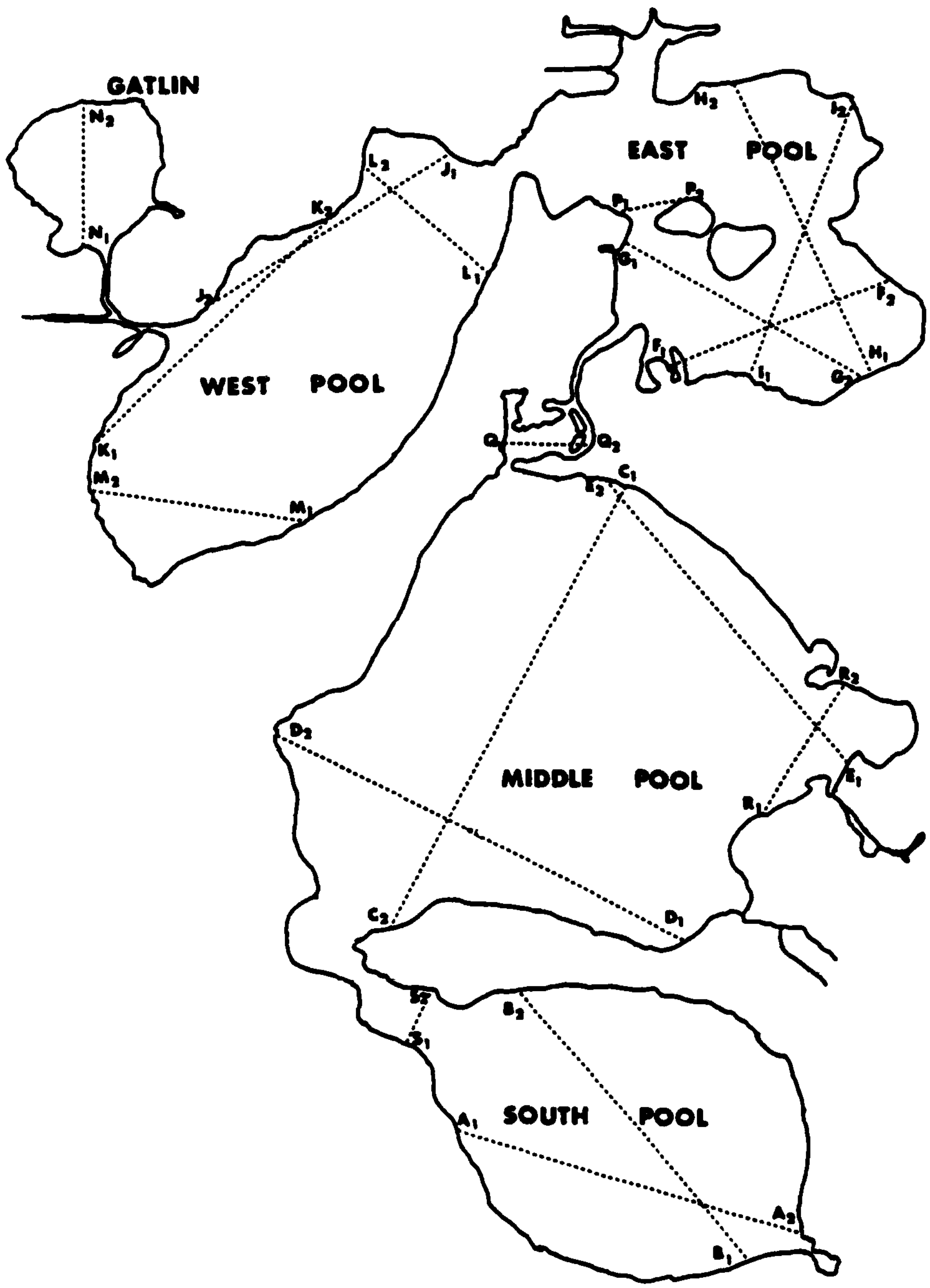


Figure 2. Lake Conway transect locations

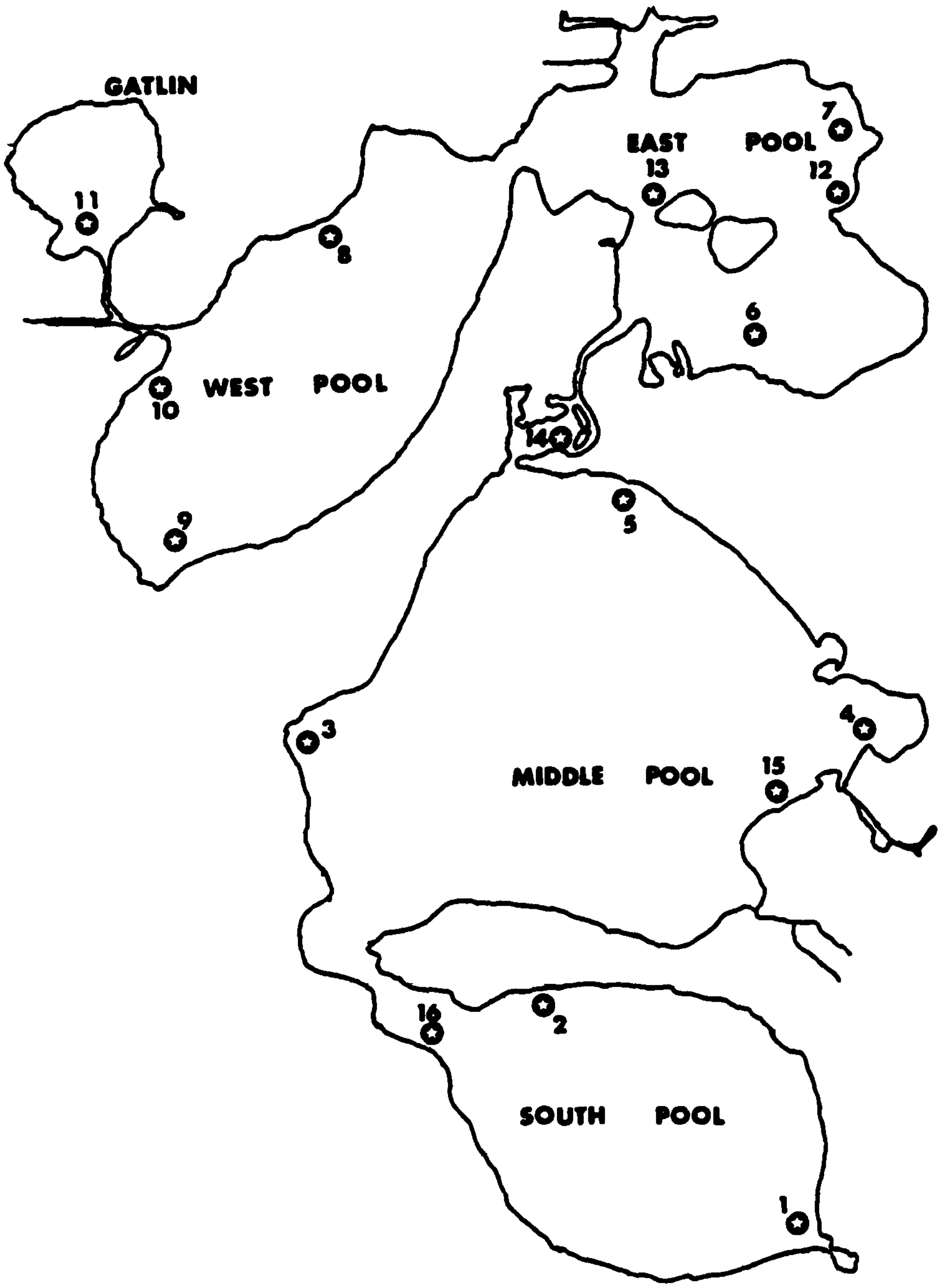


Figure 3. Lake Conway underwater plot locations

present in Lake Conway, hydrilla (*Hydrilla verticillata*), pondweed (*Potomogeton illinoensis*), nitella (*Nitella megacarpa*), and eelgrass (*Vallisneria americana*), are noted. Hydrilla, pondweed, and nitella are highly preferred but eelgrass is not controlled effectively. It was believed that eelgrass would benefit by the amur's presence. As the preferred species were eliminated, eelgrass could first expand into these areas then increase in biomass since the fish would not crop the new growth.

Transects

The major changes detected in transects are presented in Figures 4-10. Frequency of hydrilla rose to a maximum 70 percent in South Pool (Figure 4) and 55 percent in West Pool (Figure 5) midway through the first poststocking year. The hydrilla frequency then dropped rapidly and disappeared from the transects in each pool by the end of the second poststocking year. Standing crops followed the same trend. Maximum standing crop values were recorded at the end of the first poststocking year in both pools but declined steadily until only trace levels were encountered by the fifth and ninth months of the second poststocking year in West and South Pools, respectively.

Trends for pondweed in East Pool are presented in Figure 6. This pool contained the largest amount of pondweed. Both frequency and standing crop remained nearly constant (except for seasonal fluctuation) during the baseline and first poststocking year with highs of over 50 percent and 350 g/m^2, respectively. By the middle of the second poststocking year, declines were evident and were still continuing. Standing crop had not exceeded 10 g/m^2 since the third month of the third poststocking year.

Nitella, which exhibits standing crop peaks in late spring and early fall, produced a much greater biomass than any other species in the lake. Middle Pool (Figure 7) was dominated by nitella (both frequency and standing crop) and had the greatest nitella population in the lake system. Nitella was the dominant plant in South Pool (Figure 8) after hydrilla and pondweed were eliminated. The frequency of nitella remained constant with seasonal peaks of nearly 50 percent in Middle Pool throughout the project. In South Pool, nitella increased during the first poststocking year and reached its maximum frequency of 48 percent early in the second poststocking year. A decline started at the beginning of poststocking year three and frequency dropped about 10 percent during the year. Standing crop data also reflected this trend. Monthly standing crop values for the second poststocking year ranged from 220 to 700 g/m^2 and fell to the 80- to 320-g/m^2 range in poststocking year three. In Middle Pool, standing crop was nearly equal during the baseline and first two poststocking years. In the first 6 months of the third poststocking year, nitella averaged approximately 300 g/m^2 less than the same period in the previous year. However, in the last 6 months nitella averaged 25 g/m^2 higher than in the previous year.

Eelgrass is the last of the four major plant species in Lake Conway and the only one of this group not preferred by the amur. The largest

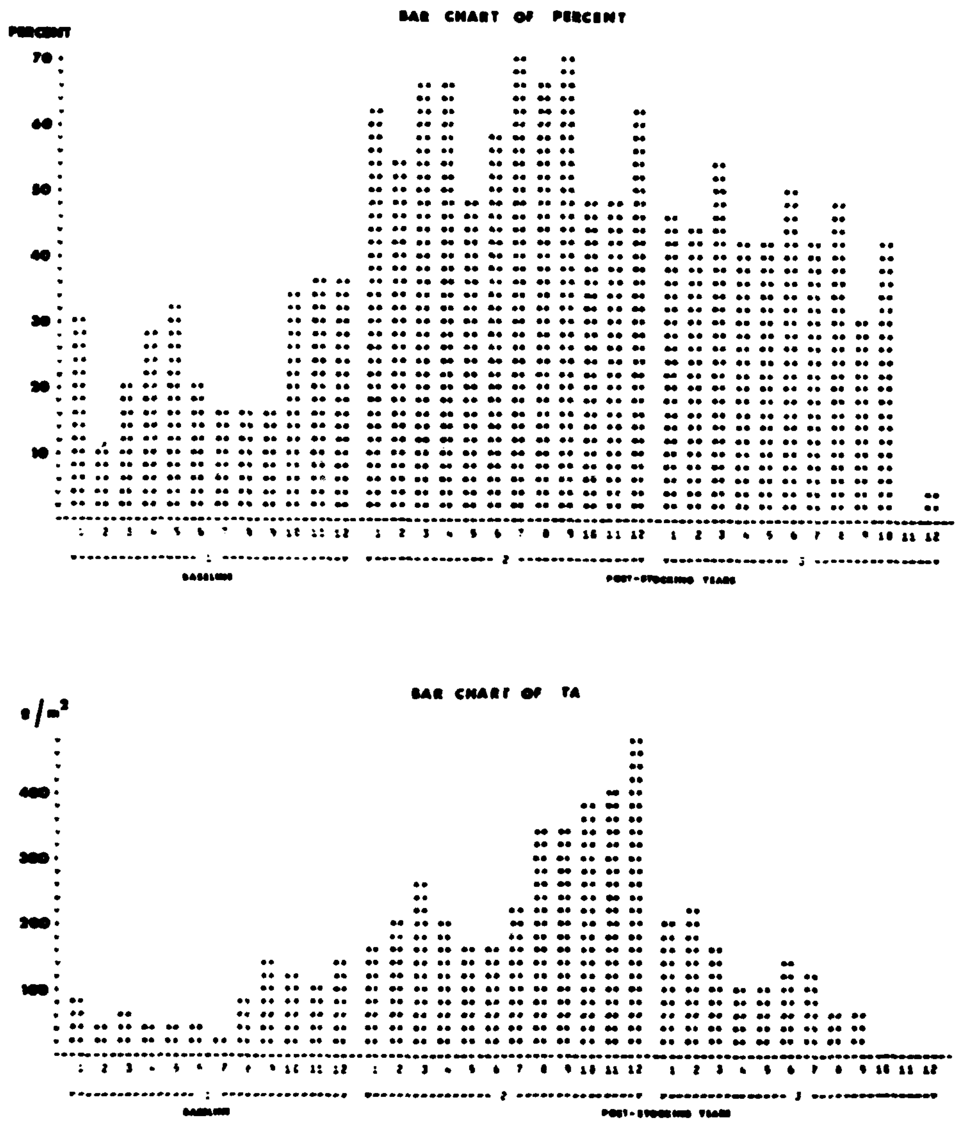
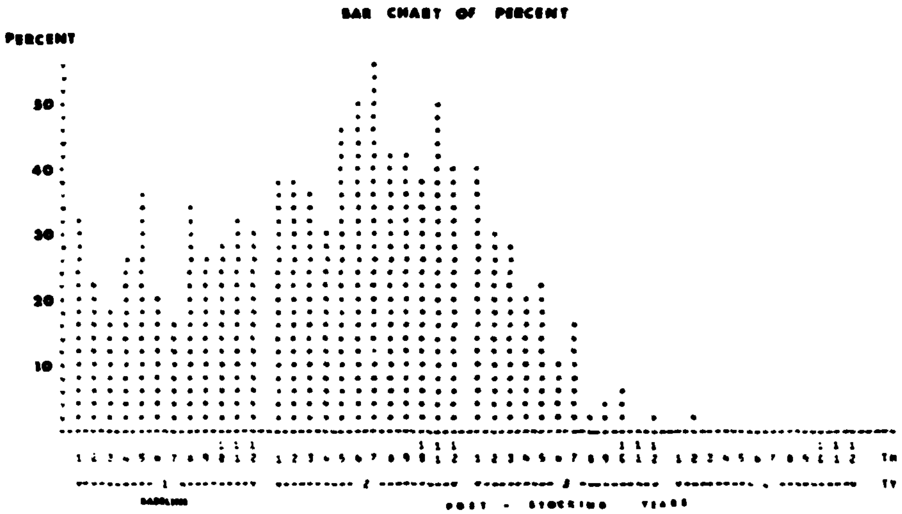


Figure 4. Transect summary results, South Pool, hydrilla



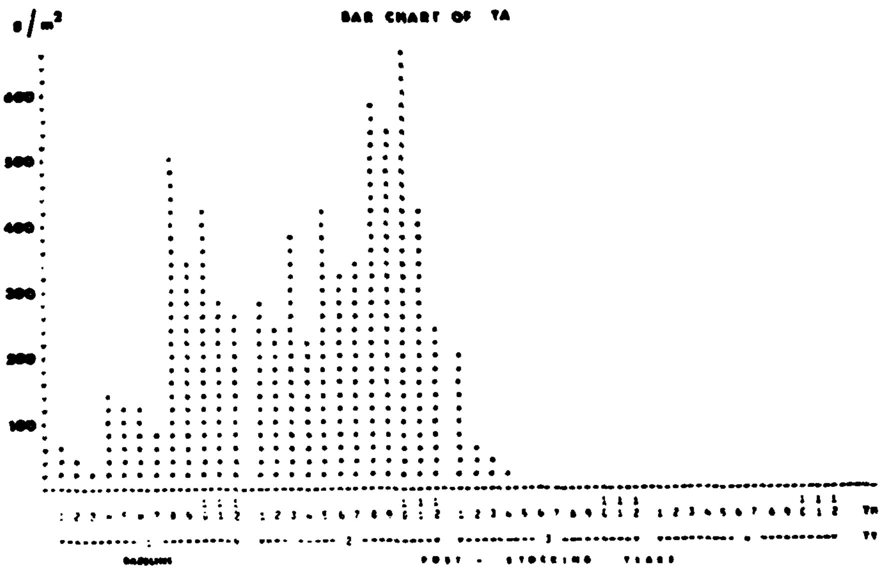


Figure 5. Transect summary results, West Pool, hydrilla

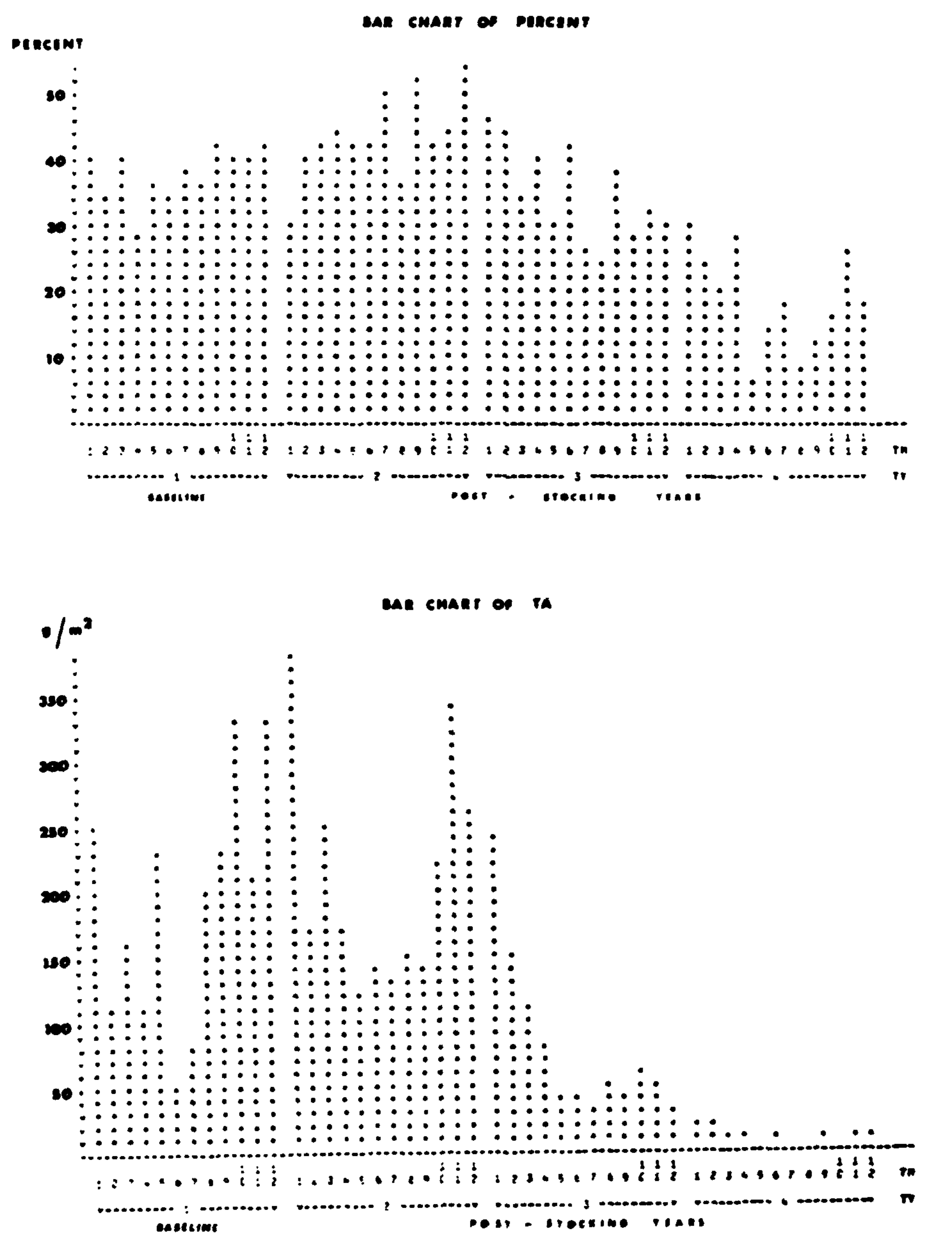
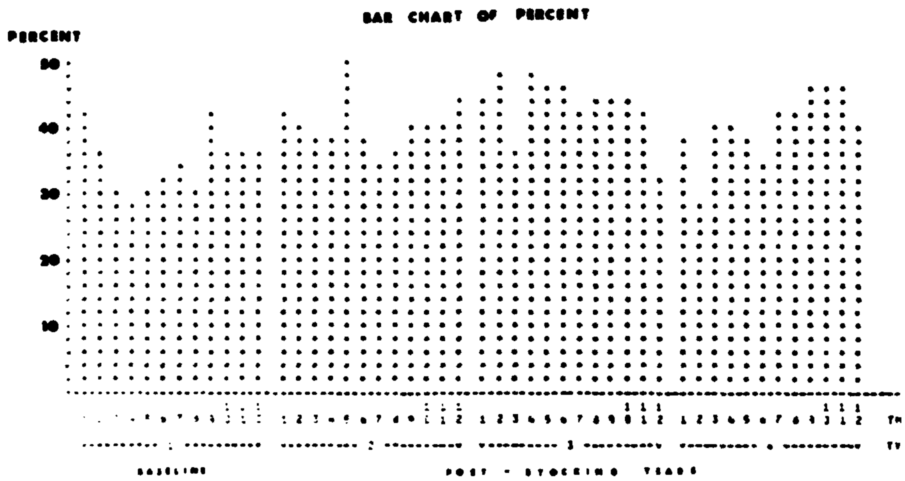


Figure 6. Transect summary results, East Pool, pondweed



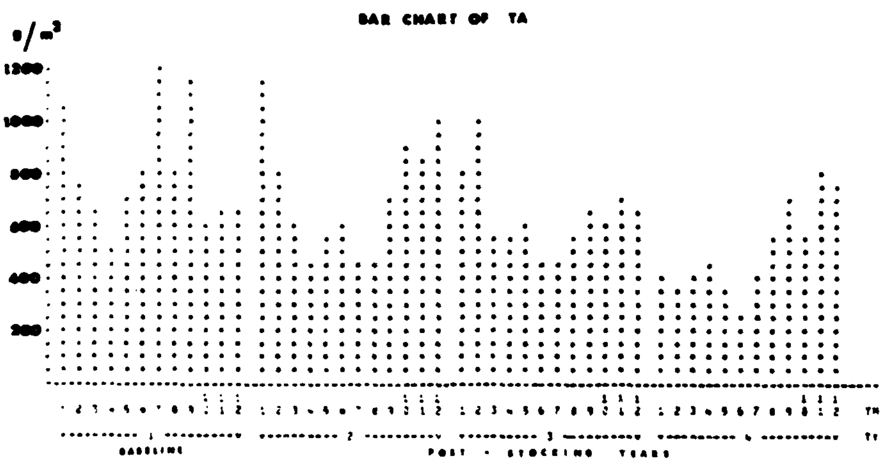


Figure 7. Transect summary results, Middle Pool, nitella

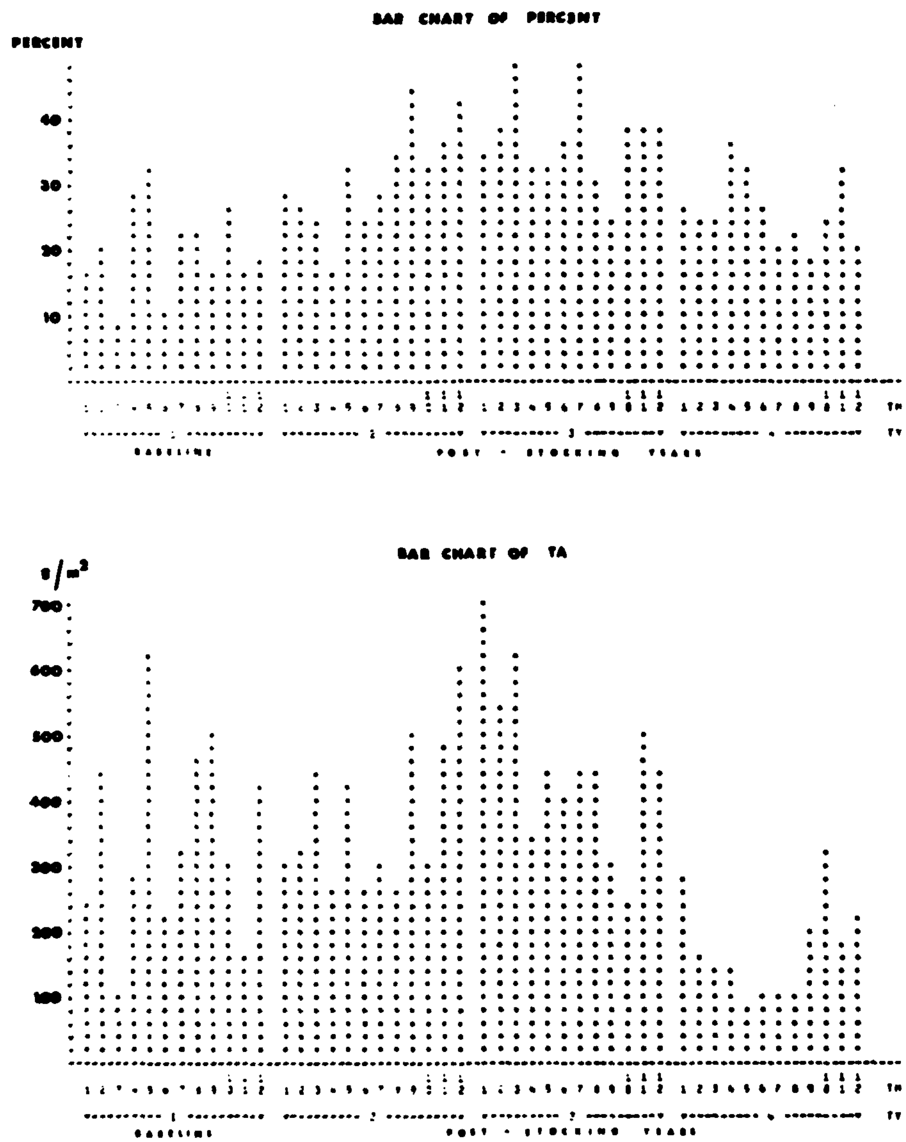
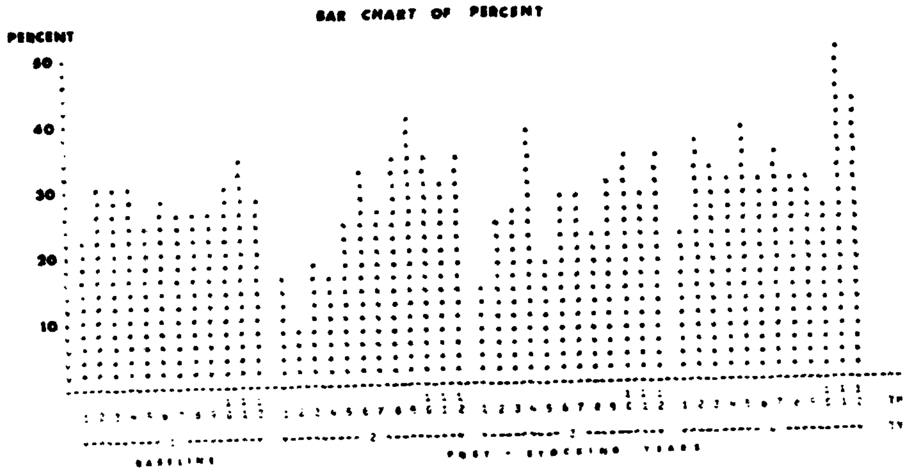


Figure 8. Transect summary results, South Pool, nitella



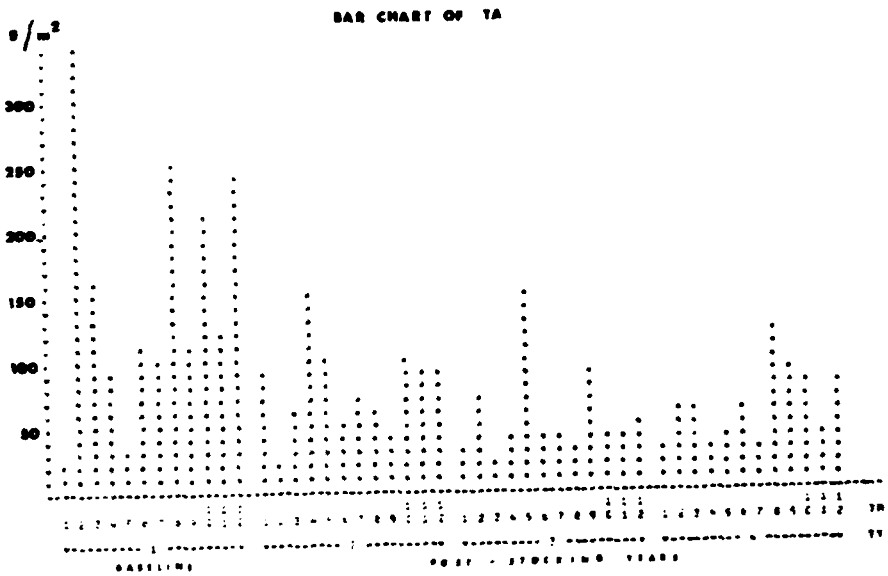


Figure 9. Transect summary results, East Pool, eelgrass

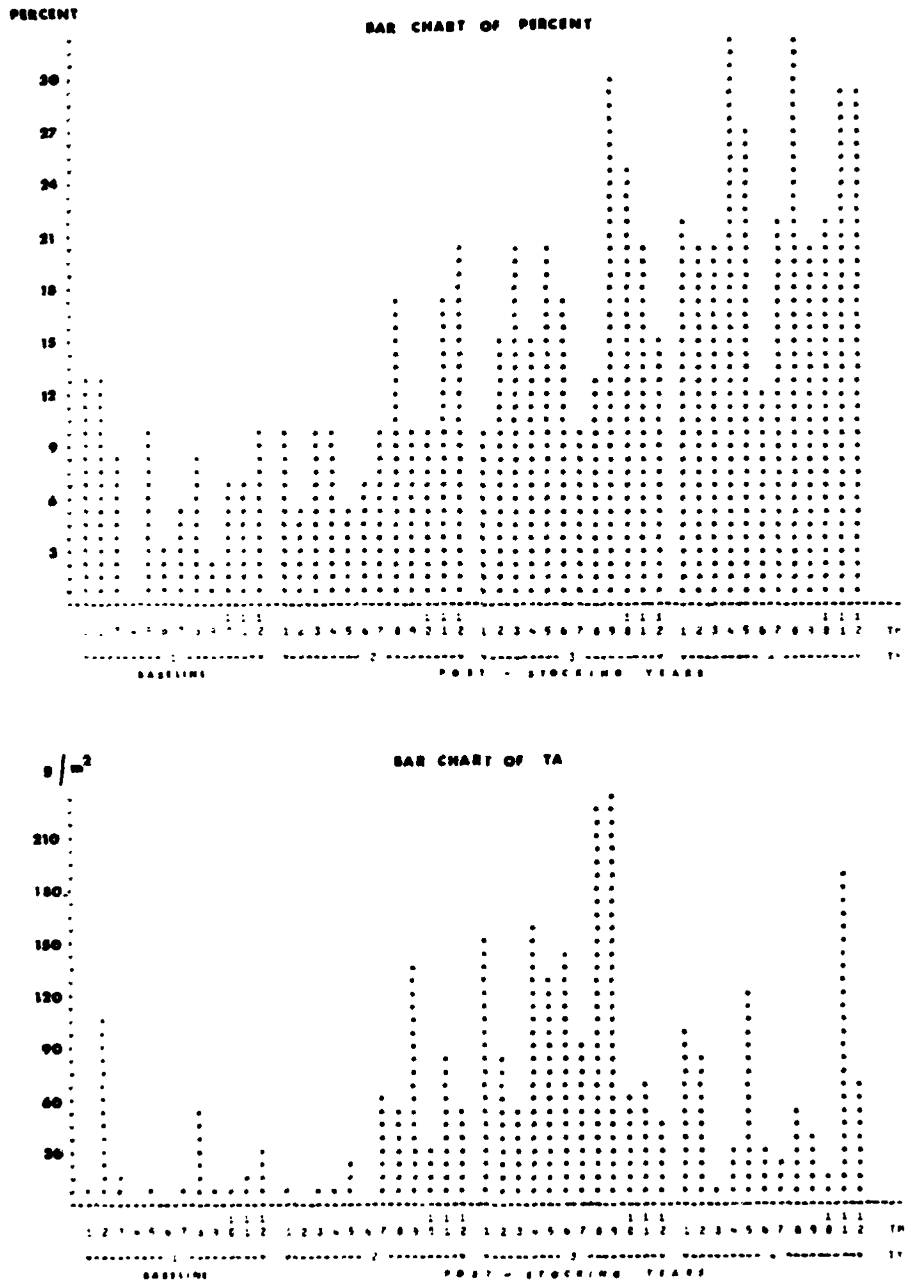


Figure 10. Transect summary results, West Pool, eelgrass

populations of eelgrass are in East and West Pools (Figures 9 and 10, respectively). Although somewhat variable, the percent frequency of eelgrass was essentially unchanged in the four study years. Eelgrass covered an average of 28 percent of the East Pool in the baseline year and increased to a 31 percent average in the third poststocking year. The standing crop in East Pool dropped immediately after the baseline year average of 150 g/m^2 but levels remained essentially constant through the three poststocking years at about 70 g/m^2. Frequency in West Pool increased midway through the first poststocking year from an average of 7 percent to 24 percent in the third poststocking year. Standing crop also increased from an average 22.5 g/m^2 during the baseline year to an average of 118 g/m^2 in the second poststocking year. During poststocking year three, standing crop dropped to 63 g/m^2.

Plots

Plot samples (Figures 11-13) show results similar to transects, but in greater detail. Plot 1 (Figure 11), in South Pool, was covered by an almost 100 percent frequency of nitella and a small hydrilla population (24 percent) in the baseline year. Hydrilla declined midway through the first poststocking year and was eliminated by the end of poststocking year two. Nitella began to decline immediately after hydrilla disappeared. Four months into study year three, no nitella was found. Only isolated stems have been found in the plot since the fifth month of the third study year.

Plot 7 (Figure 12), in East Pool, had a 25 percent frequency of hydrilla when first sampled in the baseline year. Hydrilla completely covered the plot by the beginning of poststocking year one. Stem densities and fixed heights increased to their maximum values of 1909 stems/m^2 and 1.3 m, respectively, in the ninth month of poststocking year one, but declined immediately until trace values were reached at the end of poststocking year two. Frequency also declined during this period and, although hydrilla became sparse, it did not disappear. During the second half of poststocking year three, frequency, stem densities, and fixed heights began to increase. Currently, values remain low but the population persists and has approached levels present at the beginning of the study.

Figure 13, plot 10, in West Pool, illustrates the same important point demonstrated by West Pool transects. Hydrilla was the dominant plant in this plot for the entire baseline year. The other three major species were present but often in trace amounts. As feeding pressure was exerted on hydrilla, frequency, fixed heights, and stem densities started to decrease. Hydrilla was absent from the plot by the end of the second poststocking year. At the same time, nitella, pondweed, and eelgrass increased. Midway through poststocking year two, nitella and pondweed, two preferred species, started to decline. Eelgrass, the nonpreferred species, was the dominant plant in this plot in frequency and stem density at the end of poststocking year three.

Vegetation mapping

Vegetation maps are presented in Figures 14-17 with plant coverage

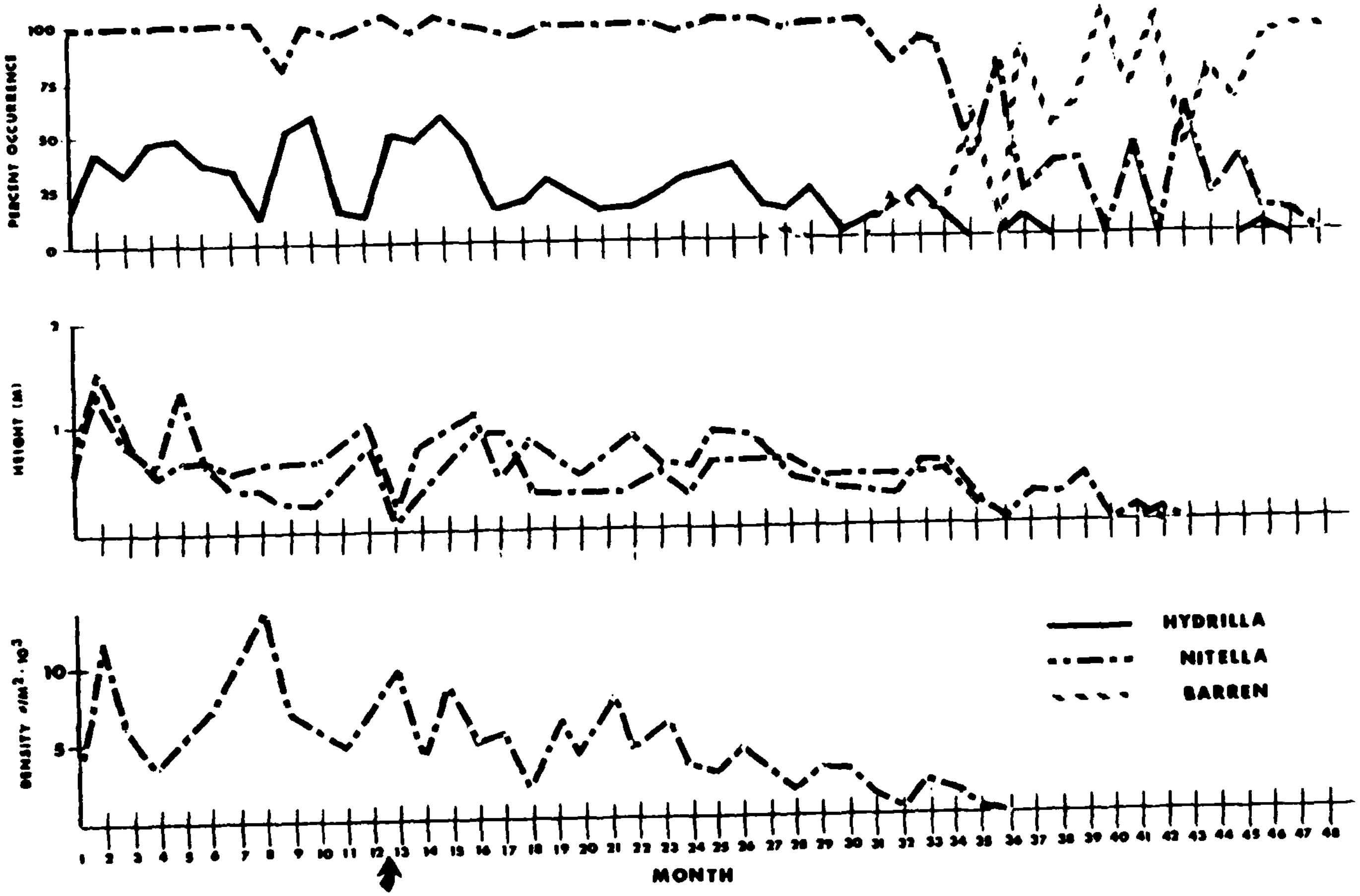


Figure 11. Plot 1, South Pool

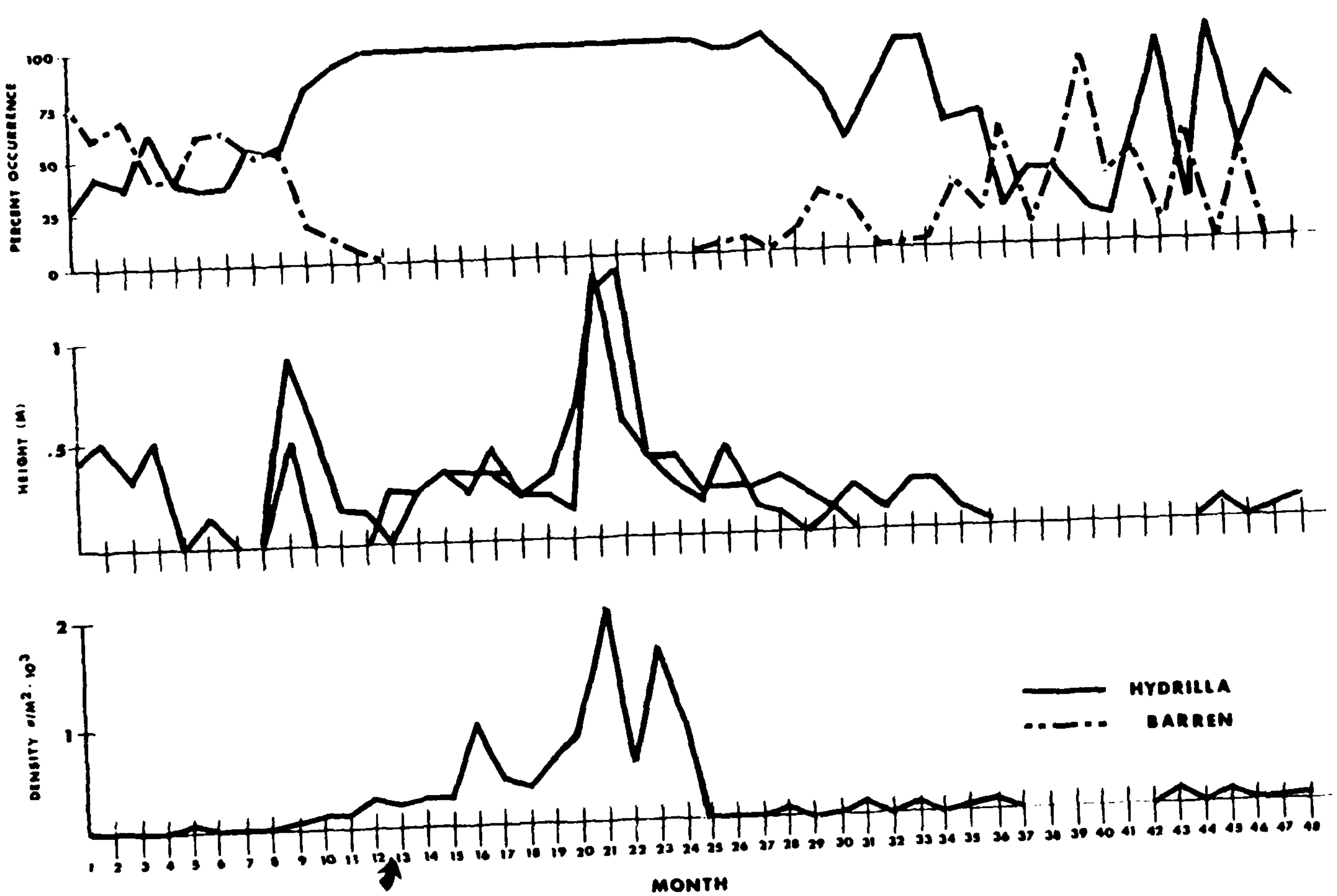


Figure 12. Plot 7, East Pool

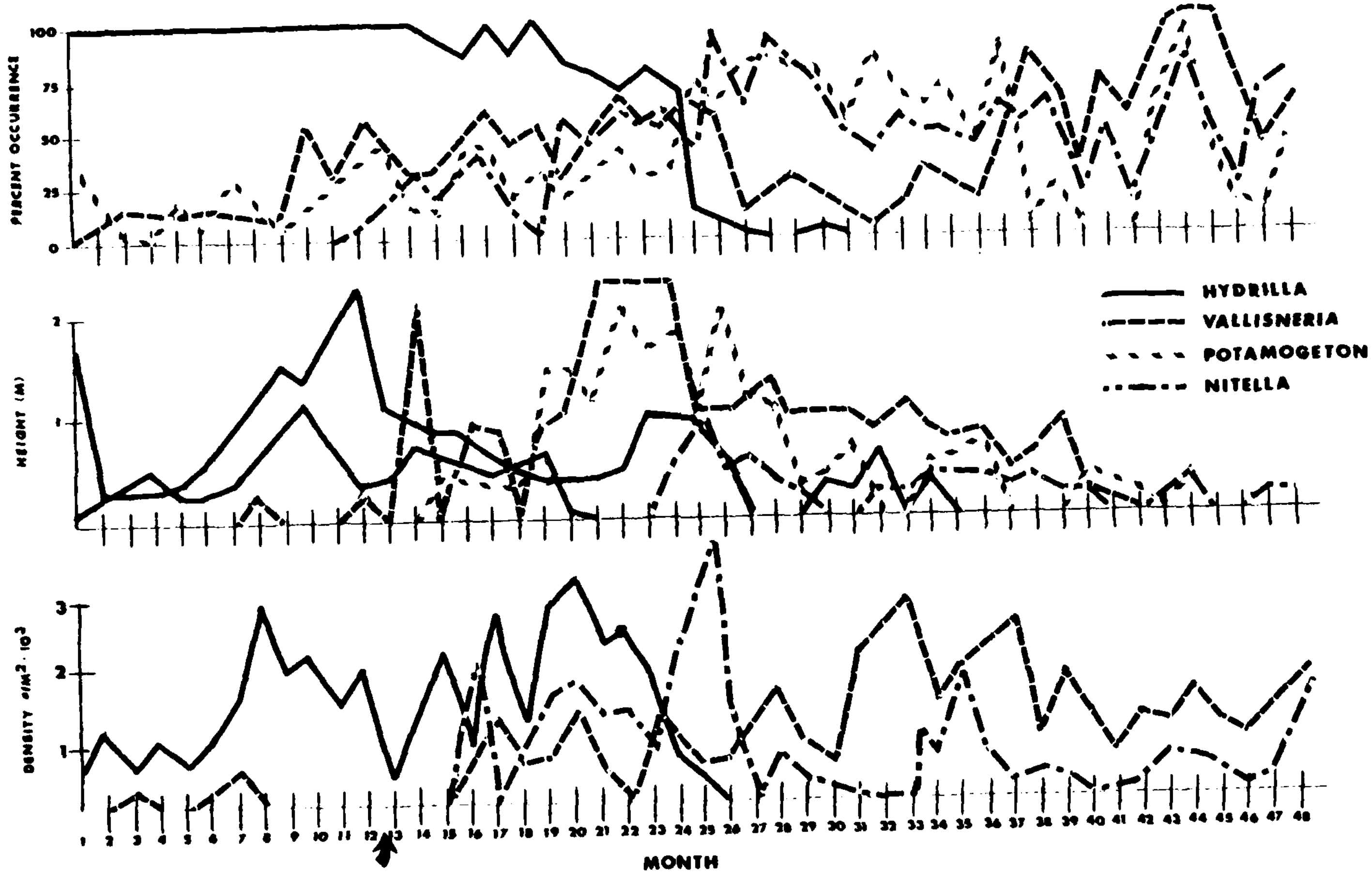


Figure 13. Plot 10, West Pool

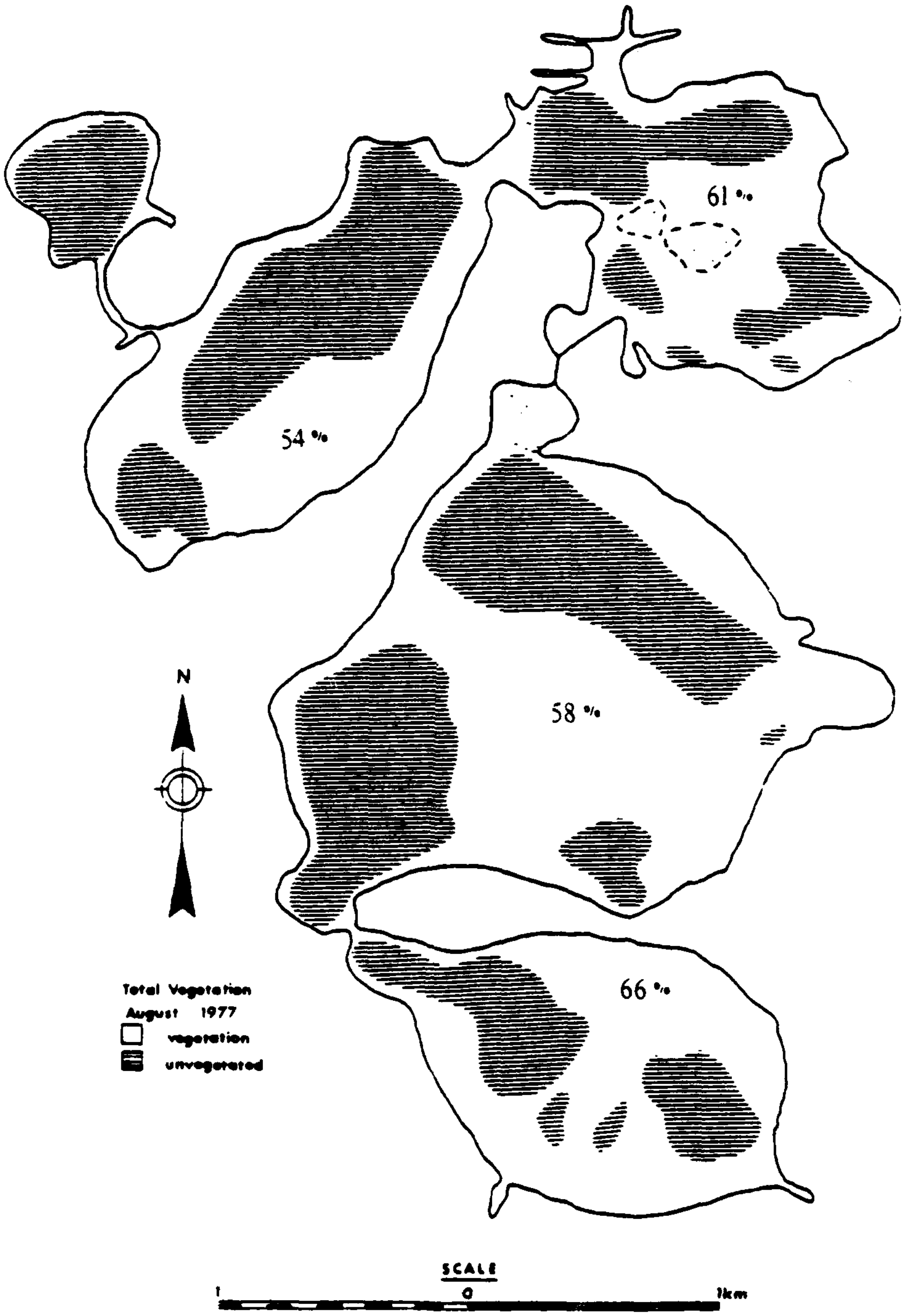


Figure 14. Vegetated area of Lake Conway prior to stocking, August 1977

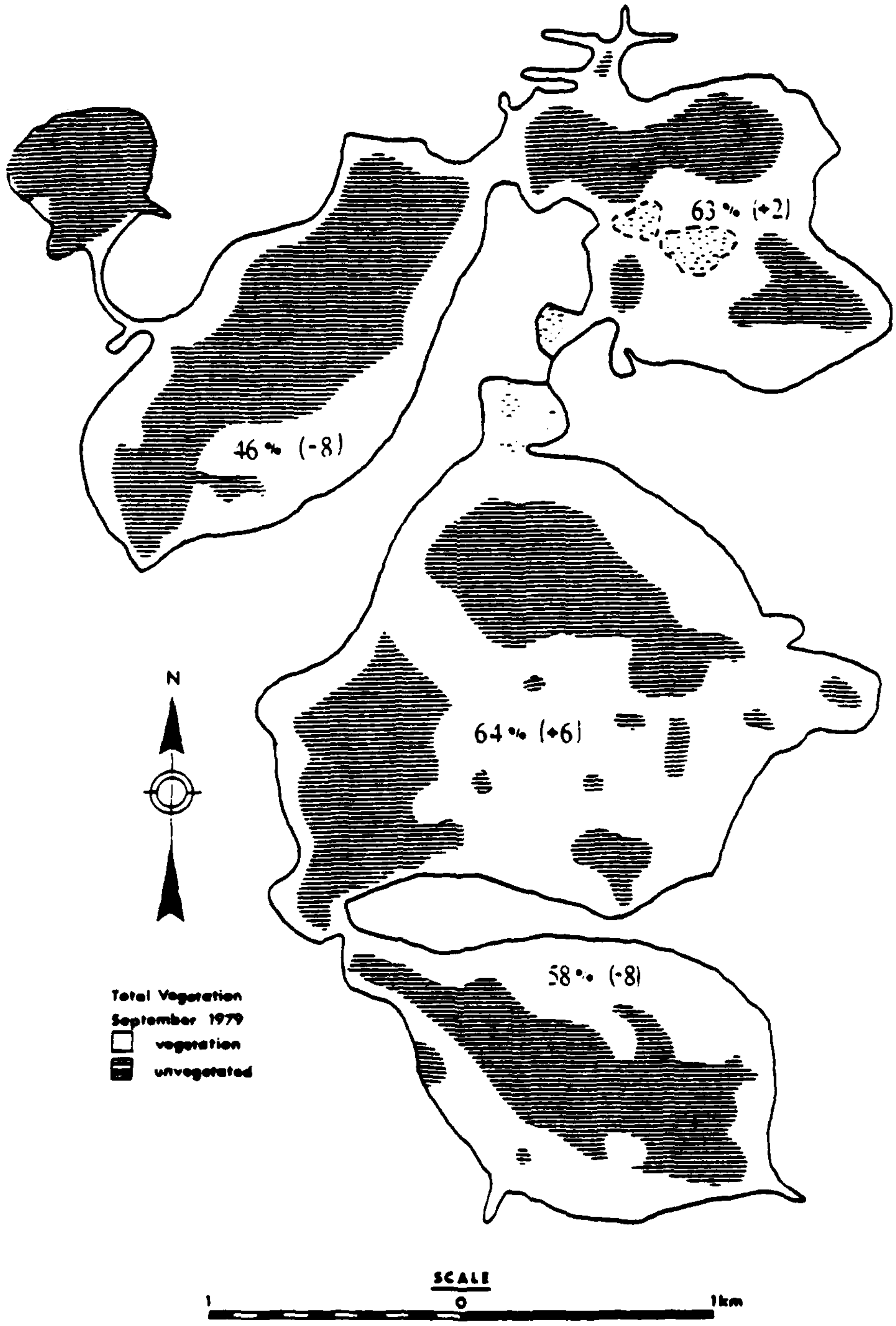


Figure 15. Vegetated area of Lake Conway 2 years after stocking, September 1979

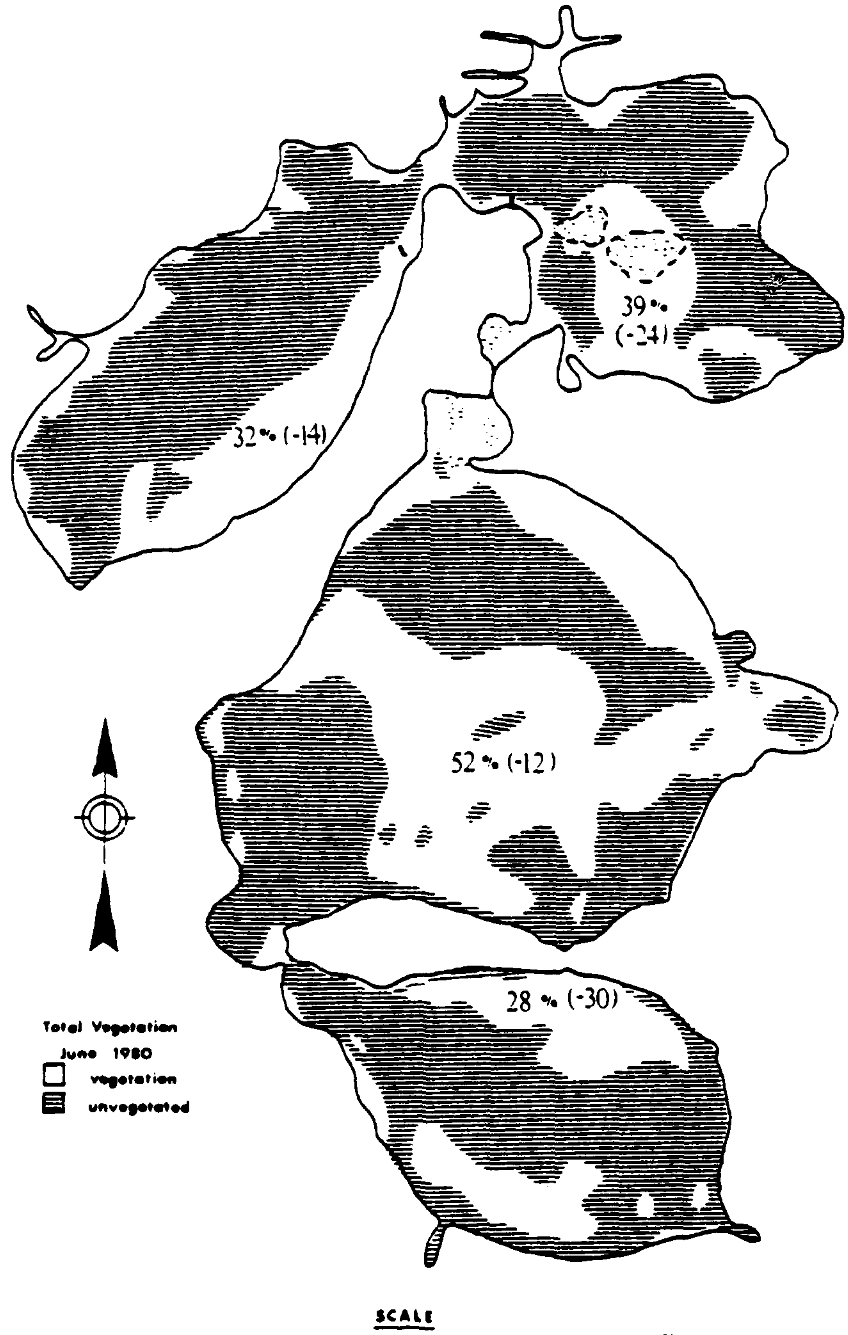


Figure 16. Vegetated area of Lake Conway during the ninth month of poststocking year three, June 1980

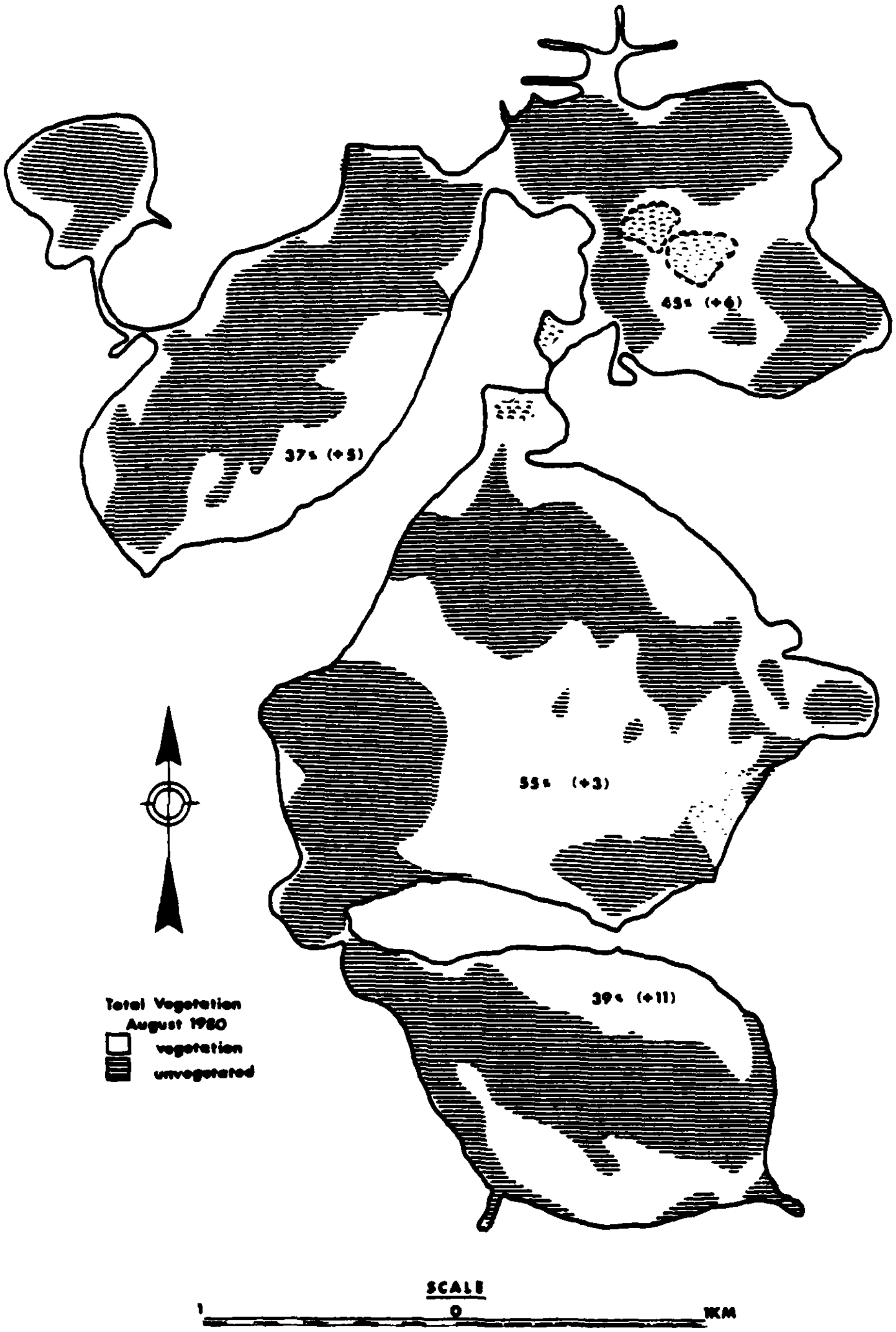


Figure 17. Vegetated area of Lake Conway by the end of August 1980

indicated for each pool. Figure 14 was prepared just prior to stocking of the amur in 1977. Two years later another map was prepared and revealed little change (Figure 15). By month nine of poststocking year three (Figure 16), vegetation had decreased by 22 percent in West Pool, 37 percent in East Pool, 6 percent in Middle Pool, and 38 percent in South Pool compared to the baseline vegetation survey. Lake Gatlin was omitted from this map since no vegetation was encountered by fathometer, transect, plot, or random sampling. Vegetation coverage increased in all pools by the end of August 1980 (Figure 17). Lake Gatlin had an increase in coverage of 34 percent between June and September 1980.

Discussion

All sampling techniques revealed a near elimination of hydrilla throughout the Lake Conway System by the end of the second poststocking year. Hydrilla was greatly reduced before the other species were affected. After the percent frequency and standing crop of hydrilla decreased, nitella and pondweed began to decline. Only the larger populations of nitella remained. Eelgrass frequency and standing crop increased in East and West Pools while other species levels declined. This increase was presumably in response to white amur feeding since fecal pellets containing fragments of some or all of the preferred species were found by divers inspecting East and West Pool plots, but very few containing eelgrass were seen. As hydrilla declined, eelgrass increased to fill the void. The trends for pondweed and nitella in West Pool (not shown) resemble hydrilla, but to a lesser extent. Eelgrass standing crop decreased during poststocking year three to an average of 63 g/m^2 from a 118-g/m^2 average in the previous year. Although the amur does not prefer eelgrass, it has been observed eating the plant. Eelgrass and nitella are the only major plant species remaining in West Pool. It is conceivable that the amur is readily feeding on eelgrass after all preferred plants are consumed.

Near the end of study year three, all pools increased in total vegetation coverage. Lake Gatlin increased by 34 percent. This dramatic increase is probably from low numbers of amur in the lake. Telemetry data indicate that the amur move more frequently as preferred vegetation availability becomes low. Large schools of amur have been seen in West Pool just outside Gatlin Canal. These are probably fish that left Lake Gatlin during low vegetation levels in the early summer of 1980.

The gradual increases in vegetation elsewhere in the system presumably are a result of amur mortality and reduced feeding rates. According to Osborne (personal communication, in a test with amur feeding on *Egeria densa*, a plant similar to hydrilla), only fish weighing less than 7 kg effectively controlled vegetation. Fish between 7 and 12 kg were able to stop vegetation levels from increasing, but those over 12 kg were not capable of achieving control. The amur in Lake Conway will probably average 12 kg or more in the fifth study year. The slight increase in vegetation coverage of the last quarter of poststocking year

three may be early evidence of loss of pondweed and hydrilla control in Lake Conway.

Acknowledgements

This work was supported by Contract No. DACW39-76-C-00[illegible] from the U. S. Army Engineer Waterways Experiment Station, CE, Vicksb[illegible] Mississippi. The authors would like to thank Ms. Gail M. Sl[illegible], Mr. Barry E. Billets, and Mr. Gregory P. Jubinsky for their technical field assistance.

Table 1

Approximate Feeding Preferences of the White Amur*,**

Greatly prefers:
* *Nitella* and *Chara* spp.
* *Hydrilla verticillata*
Najas spp.
* *Potamogeton* spp.
Duckweeds *(Lemna, Spirodella, Wolffia, Wolffiella, Azolla)*
Ceratophyllum demersum
Eleocharis acicularis
Elodea canadensis
Pithophora sp.
Will control but does not prefer:
Myriophyllum spp.
Bacopa spp.
Egeria densa
Nymphaea spp.
Polygonum spp.
Spirogyra sp.
Utricularia spp.
Cabomba spp.
Fuirena scirpoides
Brasenia schreberi
Hydrocotyle spp.
Will not control effectively:
* *Vallisneria* spp.
Typha spp.
Myriophyllum brasiliense
Phragmites spp.
Carex spp.
Scirpus spp.
Eichhornia crassipes
Alternanthera philoxeroides
Pistia stratiotes
Nymphoides spp.
Nuphar macrophyllum

* Only those species common to Florida are listed.

** Compiled from the literature. See Nall and Schardt (1978) for citations.

LARGE-SCALE OPERATIONS MANAGEMENT TEST

Fish, Mammals, and Waterfowl

by

Roy Land*

Introduction

The Florida Game and Fresh Water Fish Commission has investigated the effects of white amur (*Ctenopharyngodon idella*) on native fish, waterfowl and wading birds, and aquatic mammals on Lake Conway. This report highlights some of our findings at the conclusion of the study.

Materials and Methods

Nocturnal electrofishing was employed to sample fish populations in deeper littoral habitats. Vegetated and nonvegetated areas were sampled to assess qualitative and quantitative differences between these types of communities. Gill nets were set to sample limnetic fish. Wegener rings were used to sample shallow water fish. Blocknets were set at three sites in May and October of each study year to determine total standing crop, standing crop of sport and forage fish, and reproduction and survival of sport fish. A roving creel survey was conducted throughout the study to estimate angler effort, harvest, and success. Sampling sites are shown in Figure 1.

Foregut contents of 86 white amur were examined, and food items were quantitated volumetrically by water displacement.

Length-weight relationships, an indicator of fish condition, were compared yearly for largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*).

Numbers of individuals of waterfowl and wading bird species were counted during a complete tour of the lake from an airboat. American coots (*Fulica americana*) and ring-necked ducks (*Aythya collaris*) were collected by shotgun during the winters of 1978, 1979, and 1980. Gizzard contents were identified and measured volumetrically.

Aquatic mammals were surveyed by systematic trapping beginning in 1978. Nests of the Florida water rat (*Neofiber alleni*) were counted at four sites with nest material and adjacent vegetation noted.

Sampling procedures used are described by Guillory et al. (1978).

* Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

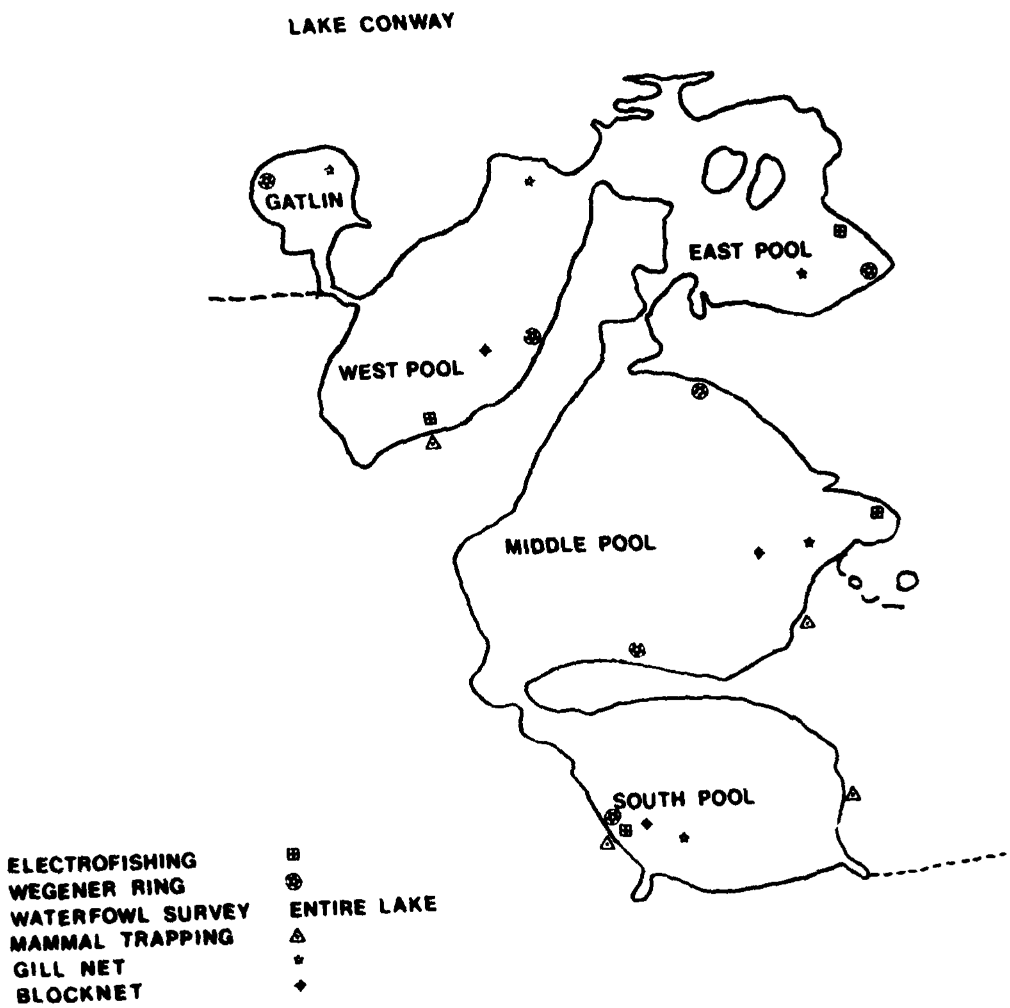


Figure 1. Sampling sites at Lake Conway

Monthly sampling was conducted until February 1978 with quarterly sampling employed thereafter. To facilitate comparisons, quarterly midpoint values from monthly data were used.

Results

Electrofishing results indicated an increase in number of fish per hour from both vegetated and beach areas (Table 1, Figures 2-3) due to greater numbers of brook silversides (*Labidesthes sicculus*). The reason for this increase is not known. Weight collected from emergent vegetated areas remained relatively constant, but weight of beach samples declined from a mean value of 12.4 kg/hr in the baseline year to 5.4 kg/hr in the first poststocking year with little variation thereafter. The decrease resulted from a decline in weight of largemouth bass, bluegill, redear sunfish (*Lepomis microlophus*), chain pickerel (*Esox niger*), and bowfin (*Amia calva*).

Gill nets indicated an abundant limnetic population of largemouth bass. A decline in catch per gill net per day was observed in the second and third poststocking years and was attributed to an increase in set time from 12 to 48 hr (Table 1). Most fish were captured at night and the increased sample interval decreased fishing efficiency. Lake Conway largemouth bass utilized the limnetic area in the absence of the extensive shallow vegetated areas common to many central Florida lakes.

Wegener ring samples revealed a depauperate shallow water fish population (Table 1). Mean number and weight collected in each year was considerably lower than totals observed in lakes in the Oklawaha and Kissimmee River Basins (Wegener et al. 1976; Holcomb et al. 1977).

Blocknet results revealed a 73 percent decrease in average total number per hectare in poststocking year III from the baseline period (Figure 4). Average numbers of sportfish per hectare declined from 7,545 in 1976-77 to 4,366 in 1979-80, and average number of forage fish dropped from 33,773 to 3,548. The decline in sportfish was due to fewer largemouth bass, while a drastic decrease in bluespotted sunfish (*Enneacanthus gloriosus*) accounted for the decline in the forage category. Total standing crop increased from a baseline mean of 103 kg/ha to 153 kg/ha in the final year, resulting from increased weight of largemouth bass, bluegill, and white amur.

The decline in total number of largemouth bass was accompanied by an increase in harvestable number and weight (Table 2, Figure 5). In general, sportfish total numbers declined, with harvestable number and weight remaining stable or increasing. Number of young-of-the-year bass (2.54 to 7.62 cm) decreased throughout the study (Figure 5); similar results were observed for bluegill and redear sunfish. Greatly reduced numbers of bluespotted sunfish followed the reduction or elimination of submersed vegetation at blocknet sites. Samples taken in May 1980 indicated that this species may be increasing with the increased vegetation observed in the last study year.

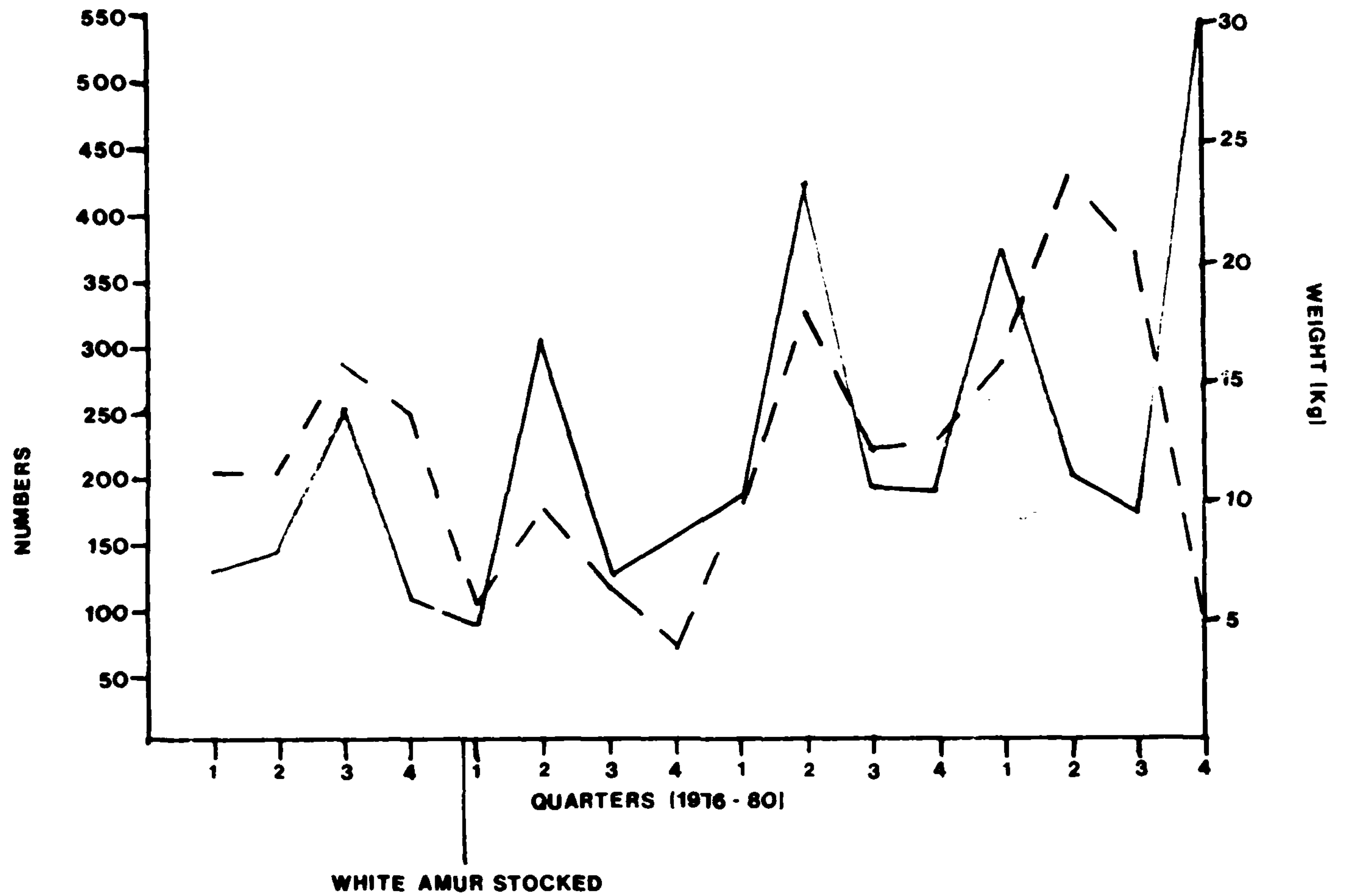


Figure 2. Averages per hour, electrofishing, vegetation

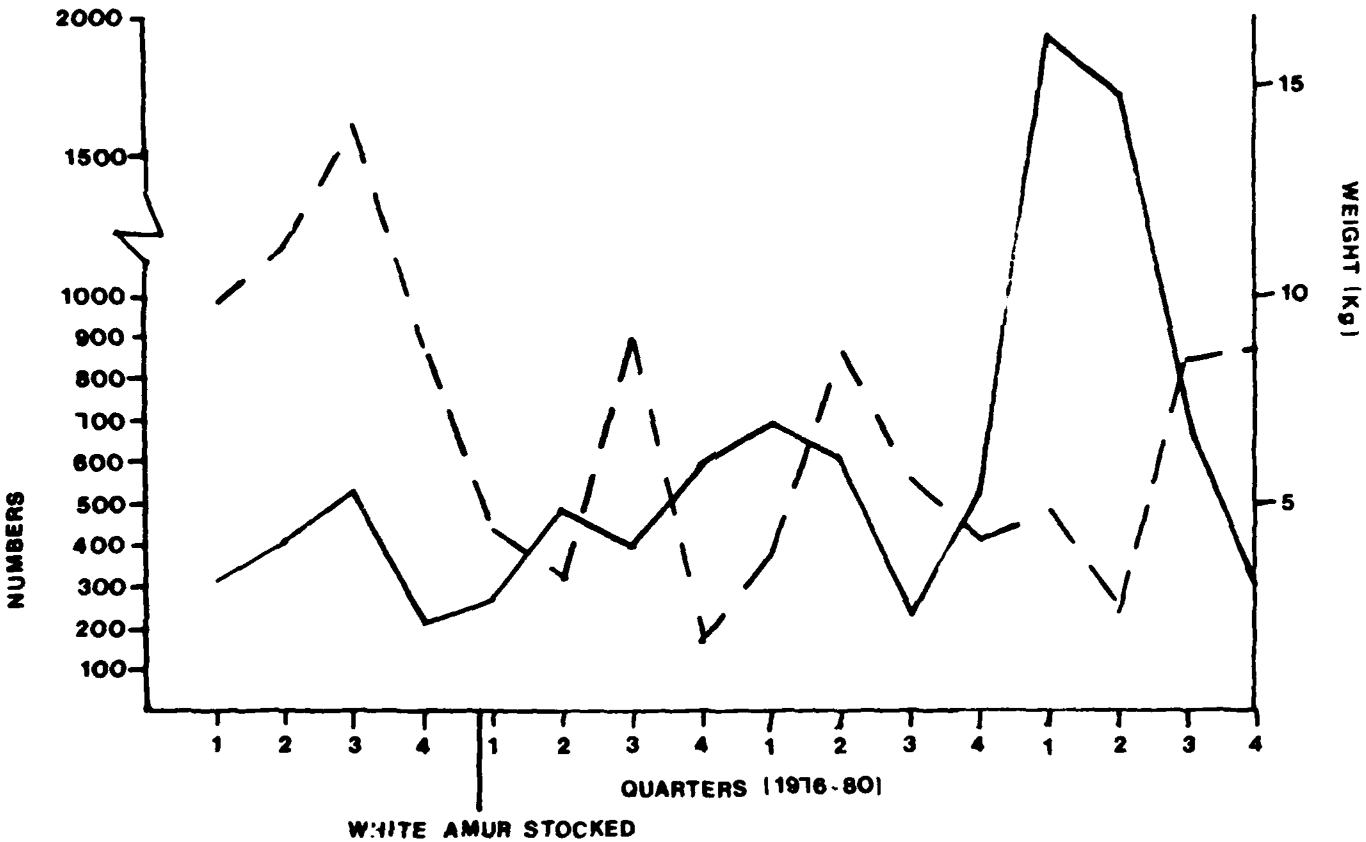


Figure 3. Averages per hour, electrofishing, beach

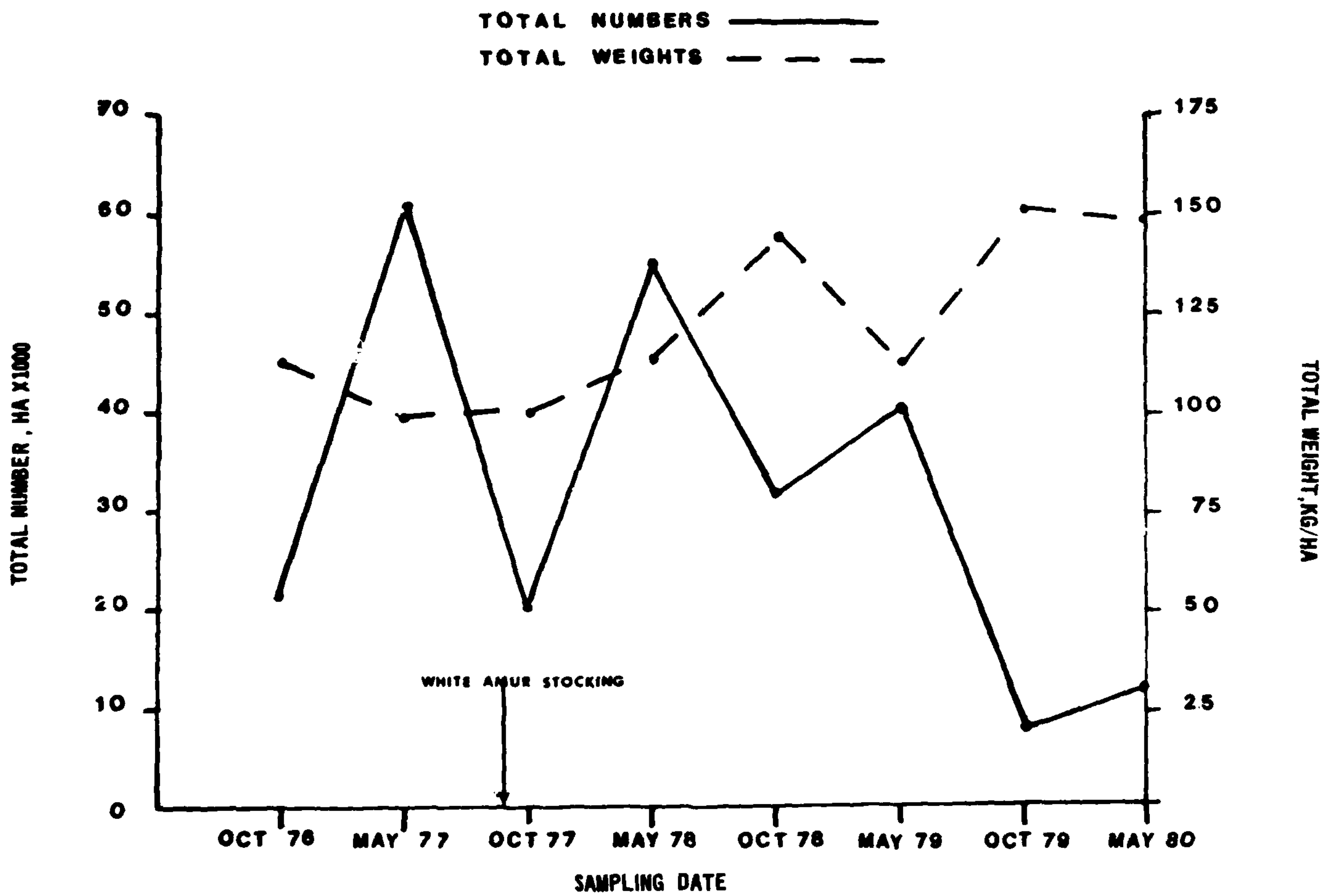


Figure 4. Blocknet samples

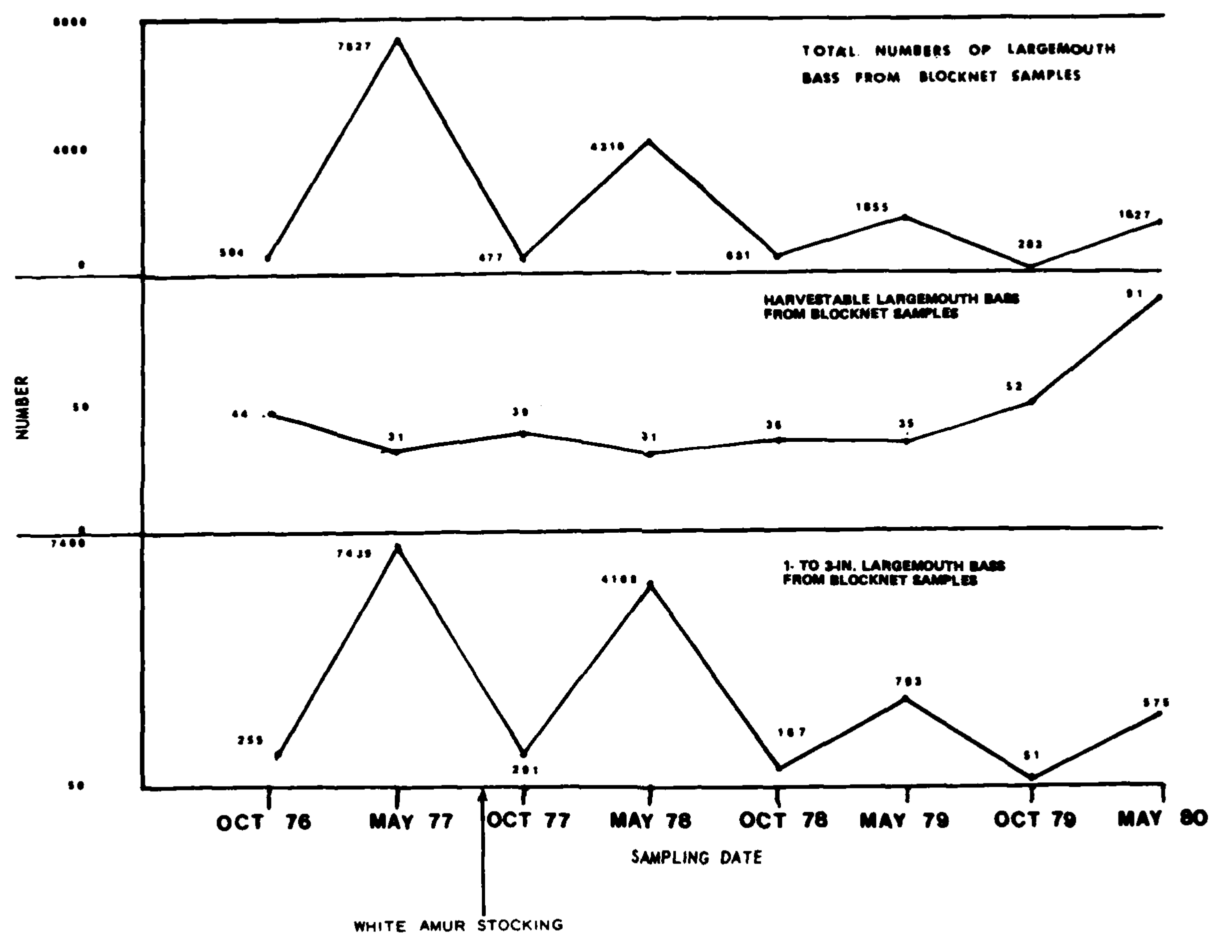


Figure 5. Largemouth bass from blocknet samples, 1976-80, Lake Conway

Largemouth bass dominated the sport fishery on Lake Conway during this study. Estimated angler success from creel survey data revealed seasonal results, but a definite increase in success beginning in fall 1978 and persisting until the final quarter of the study when a decline was observed (Table 3).

No differences in growth rate or adjusted mean weight between poststocking years II and III were observed for bass or bluegill. Land et al. (in press) reported that growth rates of bass greater than 300 mm in total length were significantly larger ($p < 0.05$) in poststocking year II than in poststocking year I. However, growth rates for bass less than 300 mm were significantly lower ($p < 0.05$) in poststocking year II than in the previous year. The authors also found no difference in growth rates or adjusted mean weight for bluegill between poststocking years I and II, but adjusted mean weight was significantly lower in poststocking year II than in the baseline year.

White amur food items for each poststocking year are presented in Table 4. The aggregate percent volume of hydrilla and nitella declined each year while the volume and frequency of occurrence of filamentous algae increased. The number of empty fish increased through the study with a marked rise in the final year.

Analysis of covariance revealed no difference between years in growth rate or adjusted mean weight of white amur. A linear growth model was determined:

$$Y = 407.4 + 14.0X$$

where

Y = total length, mm

X = month (numbered consecutively from stocking date)

Although the coefficient of determination was relatively large ($R^2 = 0.73$), examination of residuals indicated that growth was logarithmic and the initial linear phase had ended.

Hydrilla, Illinois pondweed (*Potamogeton illinoensis*), and nitella (*Nitella furcata*) were the principal food items of American coots during the study, although waterhyacinth (*Eichhornia crassipes*) was important in 1978-79. Ring-necked ducks fed heavily upon nitella, Illinois pondweed, hydrilla, and wax myrtle (*Myrica cerifera*). Snails and clams comprised the greatest volume in poststocking year III amounting to 28 percent by volume.

No Florida water rat nests were observed in the final study year. Low water levels during summer and fall 1979 forced the animals to abandon their nests and numerous burrows were observed at this time. Despite an increase in water level, no new nests were constructed. Human construction activities at sample sites reduced population abundance by

habitat destruction and are the greatest threat to aquatic mammal populations.

Discussion

In the absence of an extensive vegetated littoral zone, fish populations on Lake Conway are dependent on submersed aquatic plants to provide shelter and habitat for juvenile sportfish and forage fish. The reduction in vegetation cover that occurred in poststocking year II resulted in an increased food supply for piscivorous fishes but decreased the primary habitat of small predator fish and invertebrate organisms that comprise the food supply for young sportfish and forage species.

Little change was noted in electrofishing, gill net, and Wegener ring results. Fish which utilized emergent vegetation, open water, and shallow littoral areas were not greatly affected by the vegetation reduction. However, blocknet samples were taken in deeper areas, which, at the outset, had abundant submersed vegetation, and the effects of plant removal at these sites were striking.

The increased growth rates of largemouth bass greater than 300 mm in poststocking year II resulted from increased vulnerability of the forage base. With a greater food supply, numbers of harvestable fish increased and angler harvest and success rose during the period of minimal plant cover. Smaller bass (less than 300 mm) and bluegill exhibited a generally worsened condition after white amur stocking, attributed to the elimination of preferred habitat. The continued decline of young sportfish (2.54 to 7.62 cm) indicated adverse effects of vegetation removal. Without adequate reproduction and recruitment, the increase in harvestable sportfish, angler success, and fish condition can only be temporary, and a decline in sportfish populations is probable. Vegetation coverage appeared to stabilize in poststocking year III and fish population sample results corroborated this trend. The recent increase in submersed aquatic plant abundance may negate or mitigate the expected decline in Lake Conway sportfish populations.

The increased consumption of filamentous algae by white amur reflects decreased selectivity in older fish (Hickling 1966; Cross 1969) and reduced availability of preferred food items. The increase in number of empty fish examined and the apparent decrease in growth rate have been accompanied by a resurgence in submersed plant cover. Colle et al. (1978), Osborne and Sassic (1979), and Hardin and Atterson (in press) observed that, after an initial decrease, vegetation coverage increased between 2 and 4 years following white amur stocking. At the stocking density employed in Lake Conway, it appears that vegetation control is limited to a period of 3 years after introduction. Several authors have observed high mortality of white amur, and reduced numbers may have contributed to the loss of vegetation control.

Waterfowl and white amur examined on Lake Conway preferred the same food items. Numbers of American coots declined throughout the

study. In the final year, numbers of ring-necked ducks decreased 87 percent from the monthly average during the baseline period. Statewide waterfowl harvest data are not available for 1979-80 to determine abundance of these species. It appears, however, that the reduction of preferred food items has led to fewer numbers of overwintering waterfowl on Lake Conway.

Table 1

Yearly Mean Results for Fish Population Sampling, Lake Conway

Sampling Date	Electrofishing no./hr	Vegetation wt/hr, kg
1976-77	164	17.4
1977-78	181	7.7
1978-79	247	12.1
1979-80	323	16.0
	Electrofishing no./hr	Beach wt/hr, kg
1976-77	436	12.2
1977-78	484	5.4
1978-79	525	5.5
1979-80	1133	6.0
	Gill Net no./net day	wt/net day, kg
1976-77	31	17.8
1977-78	26	15.6
1978-79	12	8.1
1979-80	10	7.9
	Wegener Ring no./0.002 ha	wt/0.002 ha, g
1976-77	20.9	11.5
1977-78	14.9	11.6
1978-79	11.1	10.7
1979-80	23.8	20.9
	Block Net no./ha	wt/ha, kg
1976-77	41635	103.2
1977-78	37251	107.5
1978-79	38100	128.6
1979-80	11124	152.7

Table 2

Mean Number and Weight (kg) of Sportfish Collected in

0.4-ha Blocknet Samples, Lake Conway

Sampling Date	Total No.	Total Wt.	Harvestable No.	Harvestable Wt.
		Largemouth Bass		
1976-77	4015	24.9	33	17.7
1977-78	2393	23.1	35	19.9
1978-79	1243	27.3	35	16.6
1979-80	955	38.3	71	33.8
		Bluegill		
1976-77	1649	16.8	37.4	3.1
1977-78	2005	18.0	56.8	5.0
1978-79	4015	23.1	63.4	4.2
1979-80	2353	40.8	212.0	9.5
		Redear Sunfish		
1976-77	1317	20.4	67.1	10.4
1977-78	1307	19.9	73.7	17.9
1978-79	2967	40.3	44.5	8.2
1979-80	754	15.1	64.2	9.2
		Warmouth		
1976-77	519	2.8	2.6	0.4
1977-78	767	5.0	17.7	1.1
1978-79	752	4.8	13.6	0.8
1979-80	238	1.7	6.2	0.5
		Chain Pickerel		
1976-77	144	12.5	16.9	6.7
1977-78	84	8.6	18.0	6.9
1978-79	58	11.3	28.0	10.3
1979-80	50	9.0	19.0	8.1

Table 3

Estimated Effort, Harvest, and Success for Largemouth Bass Anglers, Lake Conway

	Effort	Harvest	Success
Summer 76	18038	3348	0.19
Fall 76	9688	2375	0.25
Winter 76-77	10140	1875	0.18
Spring 77	13888	4797	0.35
Summer 77	6709	844	0.13
Fall 77	13095	3976	0.30
Winter 77-78	7712	2579	0.33
Spring 78	12330	6039	0.49
Summer 78	7341	3172	0.43
Fall 78	10526	7400	0.70
Winter 78-79	10714	6026	0.56
Spring 79	11284	5863	0.52
Summer 79	4055	2284	0.56
Fall 79	7536	2963	0.39
Winter 79-80	8716	4951	0.56
Spring 80	15957	8160	0.51
Summer 80	14346	3982	0.28

Table 4

Aggregate Percent Volume and Frequency of Occurrence of Food Items of White Amur, Lake Conway, 1977-80

Food Item	Percent Volume	Frequency of Occurrence
	1977-78 Number Examined = 26	
Hydrilla	33.32	53.85
Nitella	42.40	38.46
Illinois Pondweed	53.45	73.08
Eelgrass	1.25	3.85
Filamentous Algae	1.32	19.23
Unident Vegetation	8.00	15.38
Hydracarina	0.22	7.69
Chironomidae	0.00	3.85
Empty	0.00	3.85
	1978-79 Number Examined = 22	
Hydrilla	42.01	50.00
Nitella	38.27	50.00
Illinois Pondweed	20.98	31.82
Eelgrass	4.05	9.09
Filamentous Algae	35.98	36.36
Detritus	5.65	13.64
Trichoptera	0.00	18.18
Empty	0.00	9.09
	1979-80 Number Examined = 38	
Fanwort	6.02	2.63
Hydrilla	2.01	10.53
Nitella	27.21	36.84
Pickerelweed	4.26	2.63
Illinois Pondweed	26.76	36.84
Arrowhead	2.81	2.63
Cattail	5.50	5.26
Eelgrass	4.87	10.53
Filamentous Algae	38.63	31.58
Unident Vegetation	0.80	2.63
Detritus	1.53	2.63
Mougeotia	0.00	5.26
Hydracarina	0.00	5.26
Trichoptera	0.00	2.63
Hyalella Azteca	0.00	2.63
Empty	0.00	26.32

References

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LARGE-SCALE OPERATIONS MANAGEMENT TESTS

Water Quality Analysis of Lake Conway

by

R. T. Kaleel*

Introduction

The mission of the Orange County Pollution Control Department in the Lake Conway LSOMT has been to document prestocking or baseline water quality characteristics and subsequent changes occurring since the stocking of the white amur. Additionally, the chemical and physical analyses of benthic sediments and aquatic macrophytes were undertaken.

After stocking the white amur in September of 1977, the following trends in various water quality parameters have been documented:

a. Total filtered and unfiltered phosphorus concentrations decreased.

b. Ammonia concentrations increased to levels exceeding the minimum detection level.

c. Organic nitrogen levels increased slightly or remained relatively unchanged.

d. Chlorophyll a and carotenoids changed minimally.

The purpose of this paper is to compare this past year's data (poststocking year III) with data collected during the baseline or prestocking time frame and subsequent poststocking time frames.

Operating Procedures

To accomplish this, monthly water samples were obtained from near-surface, middepth, and/or bottom levels in the water column, at 11 selected stations (Figure 1). Also, quarterly samples were obtained from stations located near the center of the respective pools. This sampling schedule was changed during the second poststocking period whereby some of the selected stations were sampled every other month. During the third poststocking time frame, sampling was conducted on a monthly basis. Table 1 lists the parameters that were selected to document water quality as well as the chemical and physical characteristics of benthic sediments and aquatic macrophytes. All water quality analyses

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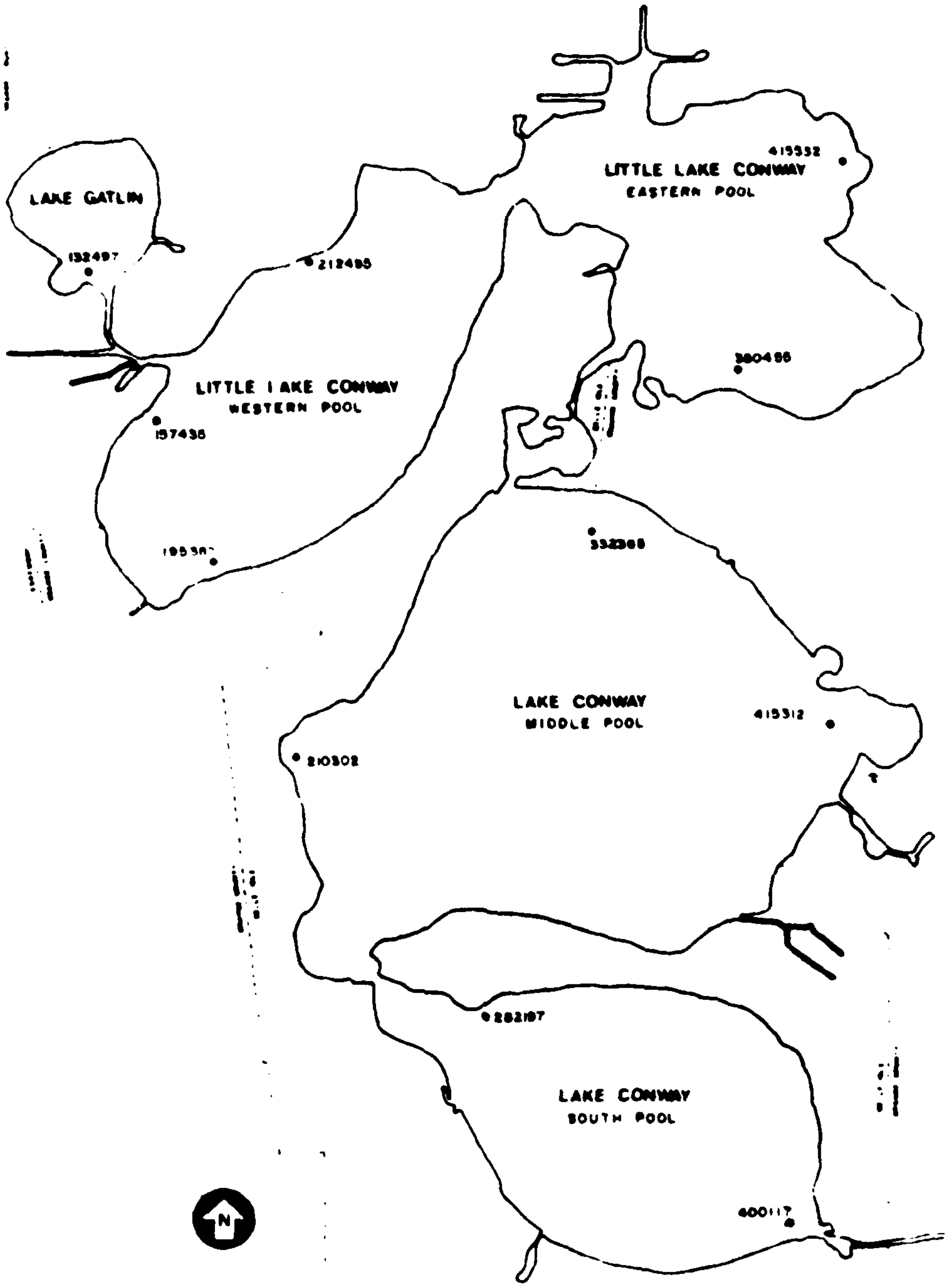

Figure 1. LSOMT sampling station locations

were performed according to the procedures outlined in Standard Methods* and Environmental Protection Agency (1976),** or were performed in accordance with procedures mutually agreed to by the Orange County Pollution Control Department and WES.

Data Analysis

South Pool

Total filtered phosphorus (TFP) has remained at the detection limit (<0.010 mg/ℓ) while total unfiltered phosphorus (TUP) has increased slightly over the previous time frame (Table 2). In both cases concentrations have remained well below those recorded during the baseline study.

At station 400117 organic nitrogen (Org-N) has remained relatively unchanged while increasing slightly at station 282197. Ammonia (NH_3-N) was recorded at below the detection limits (<0.050 mg/ℓ) for both stations during the baseline (B) and first poststocking (PSI) time frames. During the second (PSII) and third poststocking (PSIII) time frames, ammonia (NH_3-N) concentrations throughout the water column have exceeded 0.050 mg/ℓ at these stations.

Carotenoids (NAC) and chlorophyll a (CHL A) measurements have increased slightly which probably accounts for the decrease in transparency resulting in lowered secchi disk (SD) readings during this time frame (PSIII). Data collected from the middle station in the South Pool during the project seem to substantiate this trend (Figure 2), even though concentrations have remained below those recorded in the baseline.

Generally, hardness concentration of approximately 60 mg/ℓ and total solids of approximately 130 mg/ℓ showed little fluctuation throughout the project (Figure 3) in the South Pool.

Middle Pool

Total filtered phosphorus concentrations have remained below detection limits (<0.010 mg/ℓ) except for occasional samples obtained from the mid pool station and station 415312 (Table 3). Total unfiltered phosphorus concentrations have remained relatively unchanged compared to the previous time frame (PSII) but are less than baseline concentrations.

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* American Public Health Association, American Water Works Association, Water Pollution Control Federation. 1976. Standard Methods for the Examination of Water and Wastewater, 14th ed., American Public Health Association, Washington, D. C.

** U. S. Environmental Protection Agency. 1976. "Methods for Chemical Analysis of Water and Wastes," EPA-625/6-74-003a, Environmental Monitoring and Support Laboratory, Environmental Research Center, Cincinnati, Ohio.

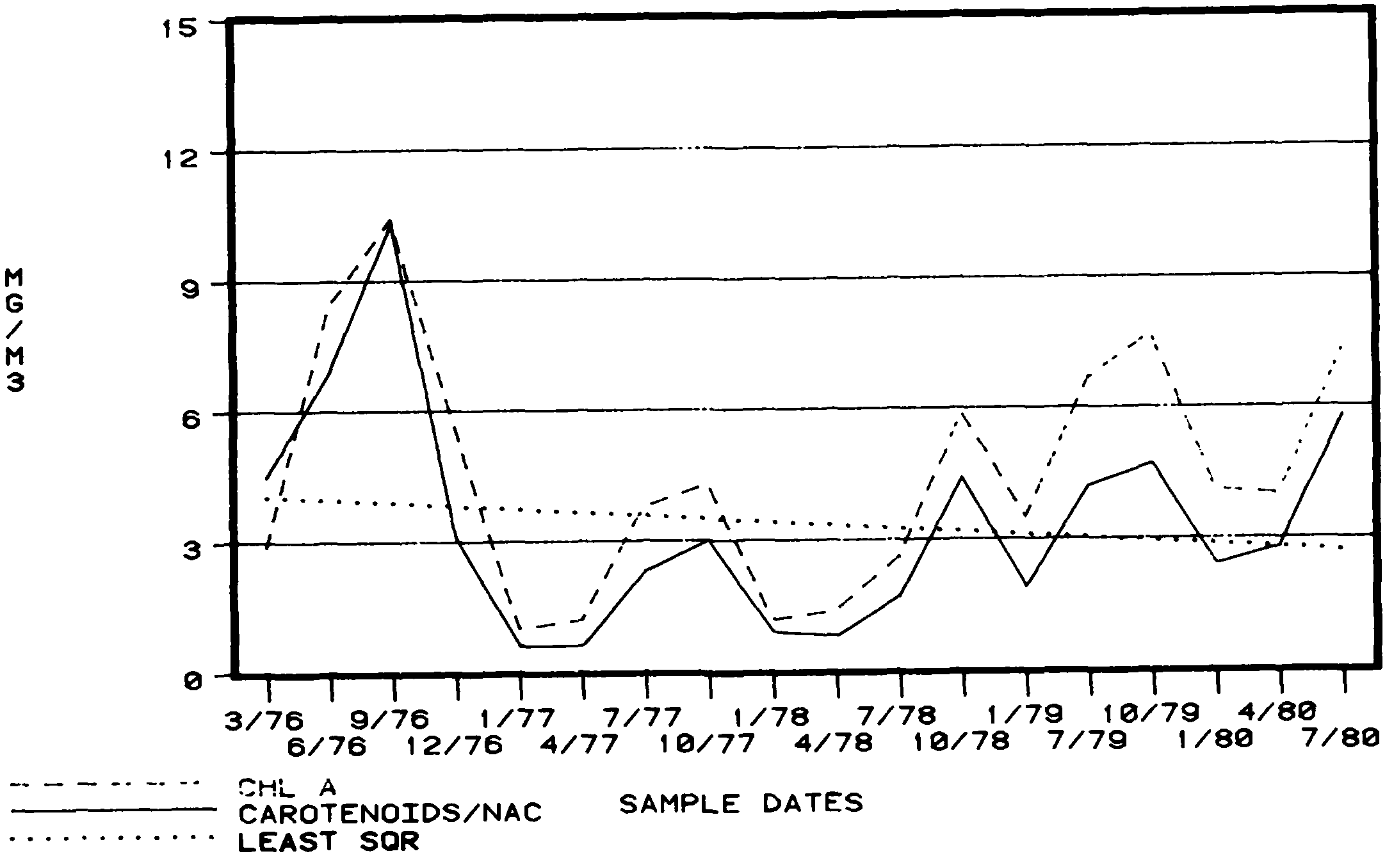

Figure 2. LSOMT South Pool-Mid CHL A and NAC surface samples

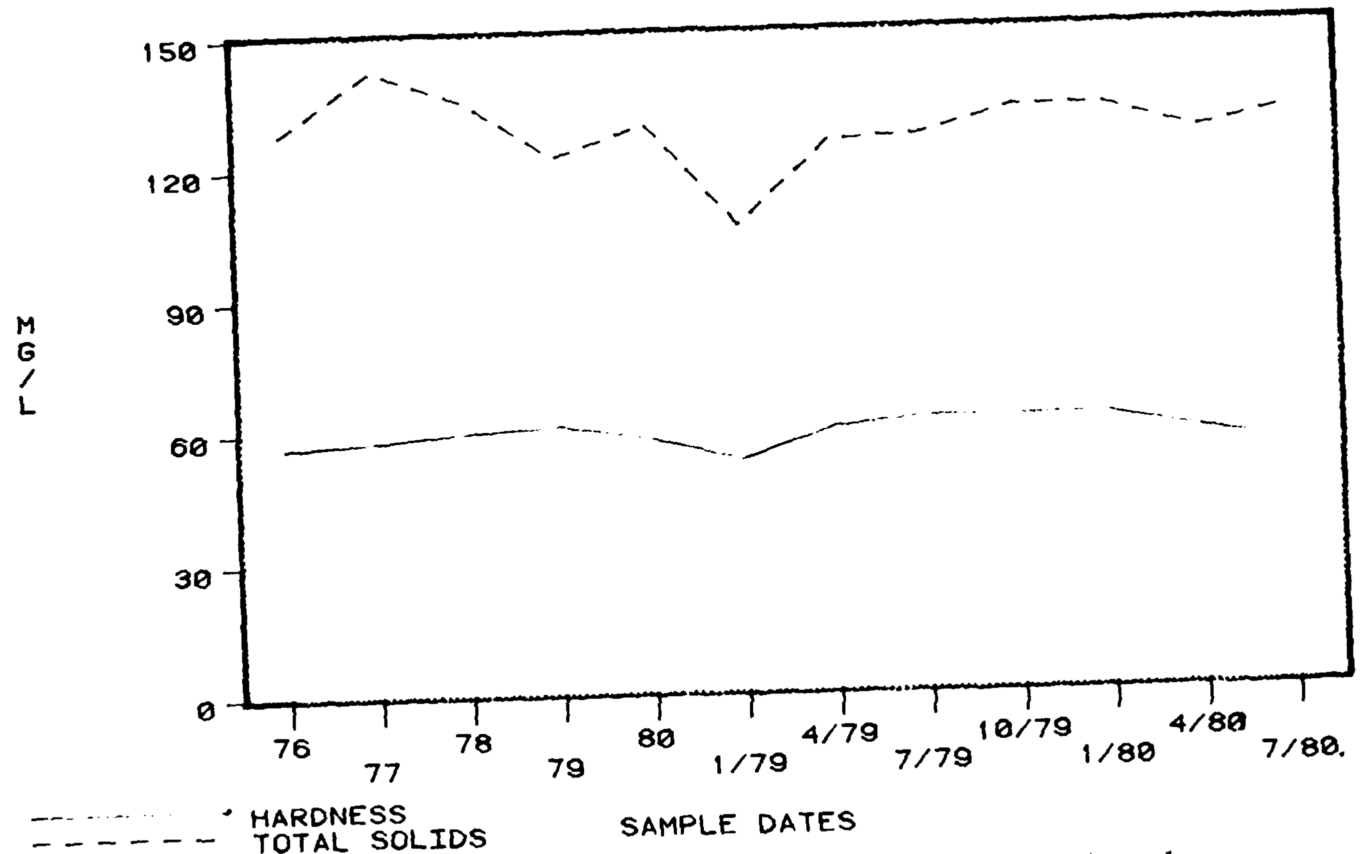

Figure 3. LSOMT South Pool-Mid (yearly averages of hardness and total solids concentration followed by quarterly results)

Organic nitrogen concentrations have increased slightly over baseline concentrations but have remained relatively unchanged since September of 1978 (PSII, PSIII). Ammonia concentrations have remained relatively unchanged when compared to the preceding time frame (PSII) but have consistently exhibited higher concentrations when compared to baseline data.

Cholorphyll a and carotenoids have minimally increased at all stations in this pool throughout the project (Figure 4). While chlorophyll a and carotenoids have exceeded baseline concentrations, the levels have generally remained below 10 mg/m^3 (Figure 4).

Hardness (as $CaCO_3$) and total solids have fluctuated minimally throughout the project and measurements have been consistently reported around 60 mg/ℓ and 130 mg/ℓ, respectively (Figure 5).

East Pool

On several occasions total filterable phosphorus (Table 4) exceeded the detection limits at stations 380455 and 415532 compared to the middle station where TFP exceeded 0.010 mg/ℓ once. This represents a slight increase in this parameter over the previous time frame (PSII) but concentrations have varied concomitantly with the filtered fraction.

Organic nitrogen concentrations have decreased slightly throughout the project. Current levels are below those recorded during the preceding time frame (PSII) and the baseline. Ammonia concentrations are relatively unchanged from the previous time frame (PSII) but exceed those recorded during the baseline and first poststocking time periods (Table 4).

Chlorophyll a and carotenoids concentrations are currently slightly below those recorded for the previous time frame but show relatively little change when compared throughout the project (Figure 6).

Hardness and total solids concentrations have shown moderate fluctuation throughout the project. Hardness and total solids concentrations of approximately 65 mg/ℓ and 145 mg/ℓ, respectively, are representative (Figure 7).

West Pool

Total filtered phosphorus concentrations (Table 5) reported for stations 212495, 195382, and 157435 were below or at the detection limit (0.010 mg/ℓ). Again similar concentrations were reported for the middle station except once, when concentrations exceeded 0.010 mg/ℓ. Total filtered and unfiltered phosphorus concentrations are relatively unchanged from the second poststocking (PSII) interval but are well below baseline concentrations.

Organic nitrogen concentration has remained relatively unchanged at stations in the West Pool throughout the project. Concentrations of ammonia decreased from the previous reporting period (PSII), but were consistently higher than 0.050 mg/ℓ (detection limit) reported as the baseline level.

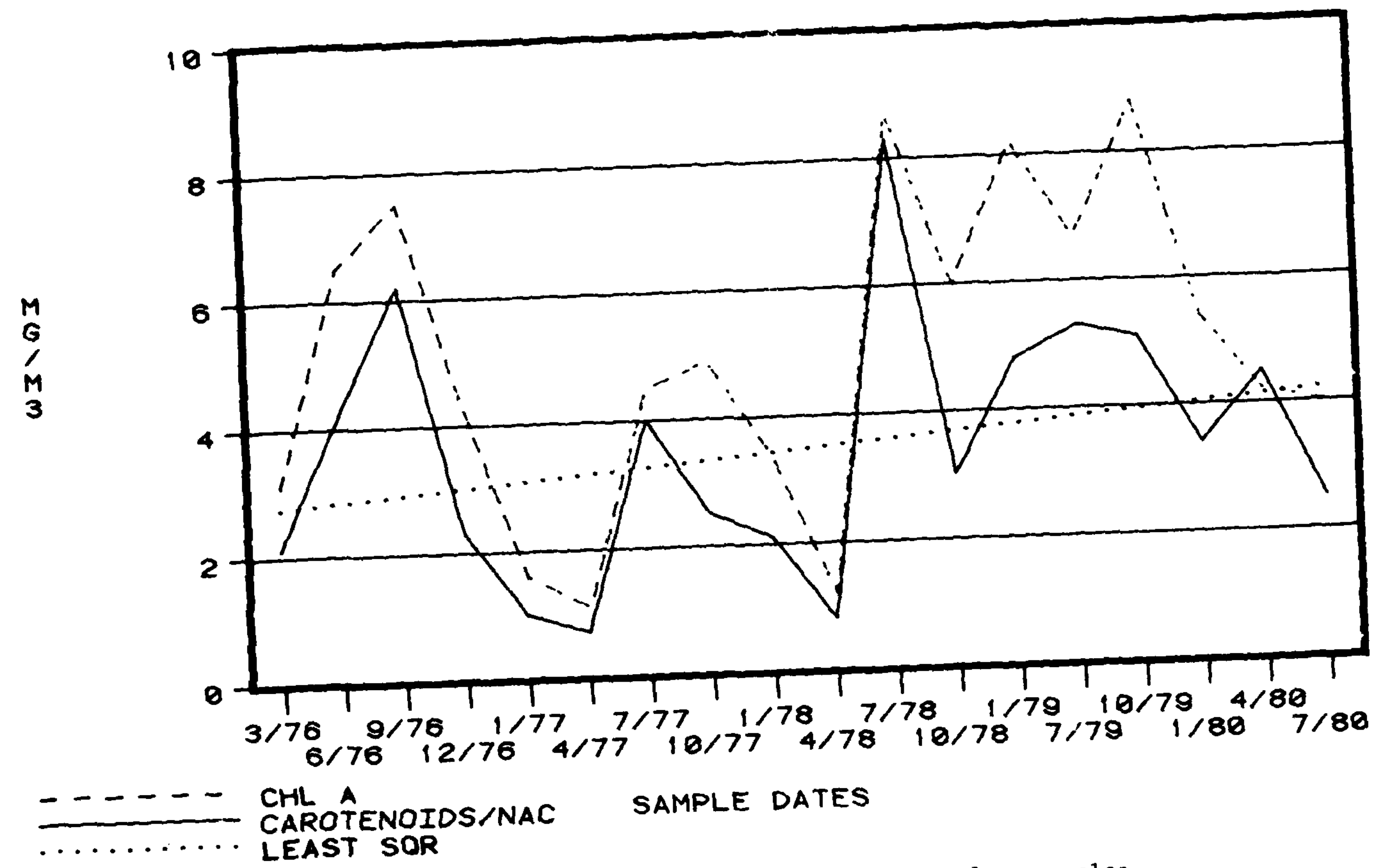

Figure 4. LSOMT Middle Pool-Mid CHL A and NAC surface samples

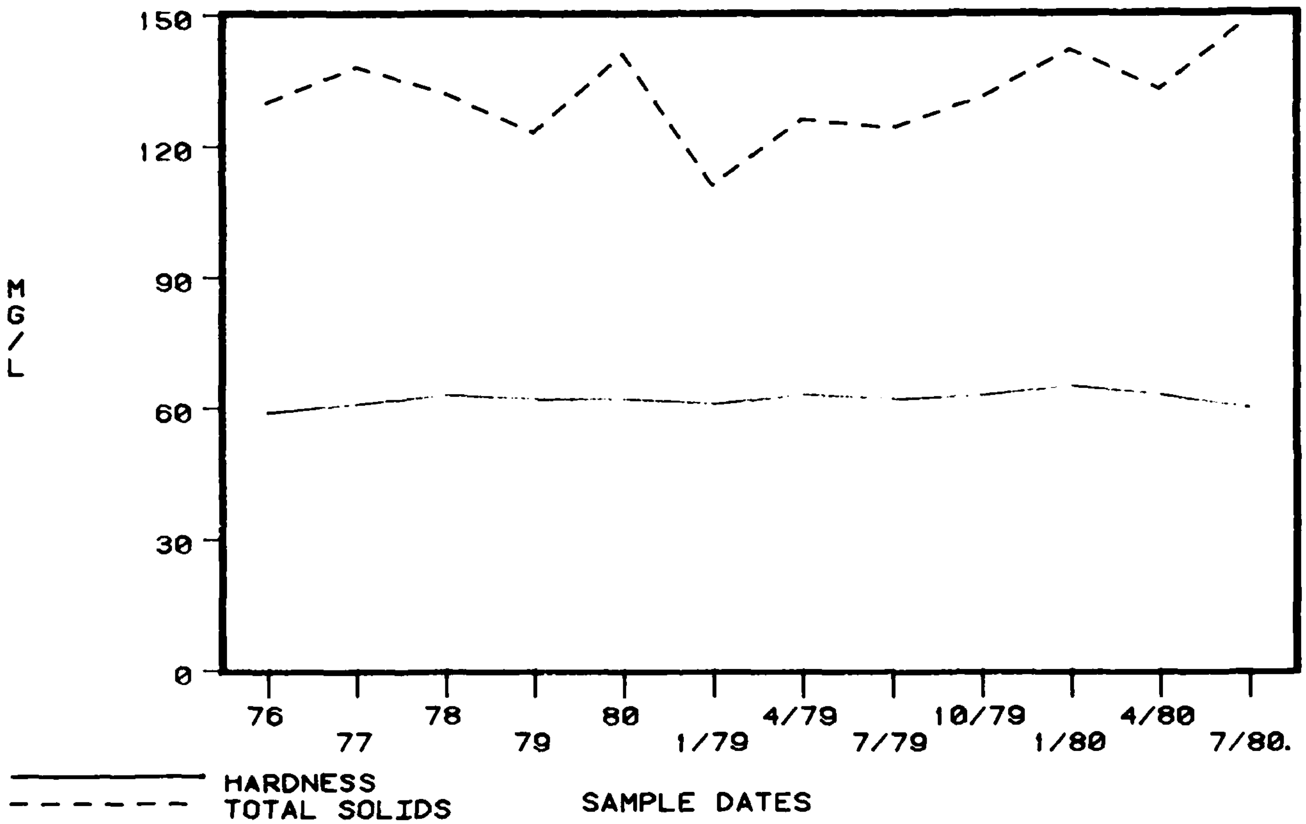

Figure 5. LSOMT Middle Pool-Mid (yearly averages of hardness and total solids concentration followed by quarterly results)

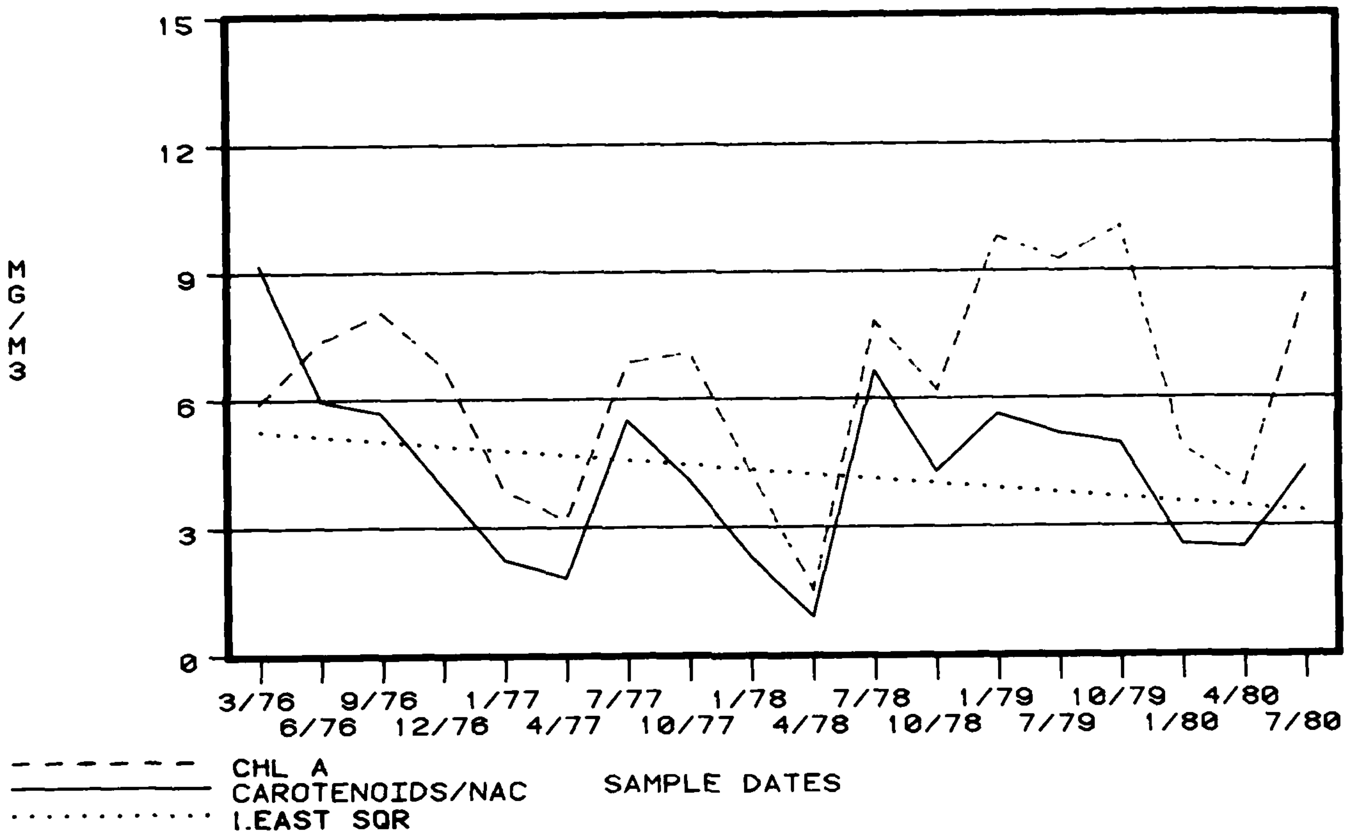

Figure 6. LSOMT East Pool-Mid CHL A and NAC surface samples

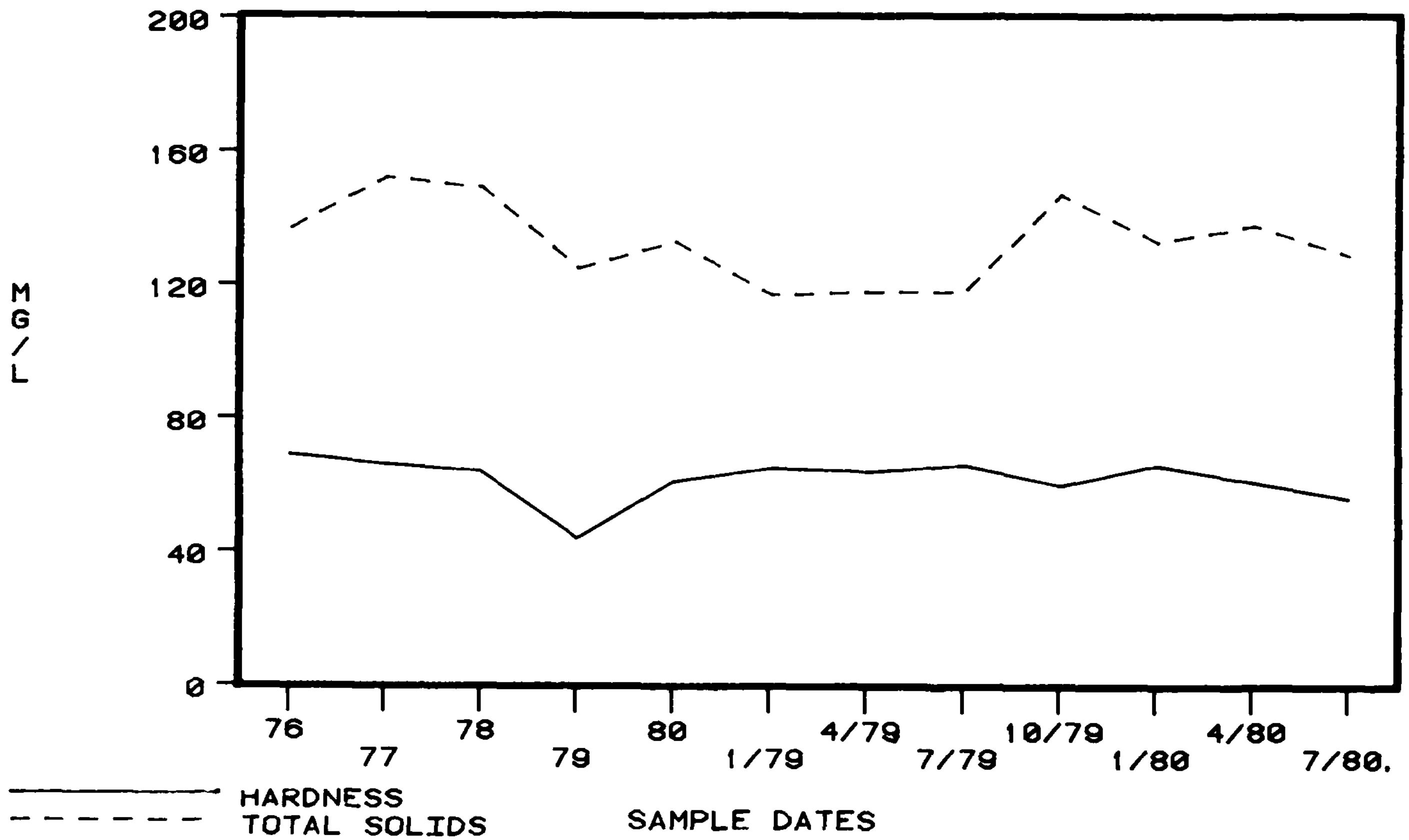

Figure 7. LSOMT East Pool-Mid (yearly averages of hardness and total solids concentration followed by quarterly results)

Figure 8 indicates that chlorophyll a and carotenoids have fluctuated widely and have exceeded baseline levels on several occasions.

Total solids and hardness concentrations have fluctuated minimally throughout the project in the West Pool (Figure 9).

Lake Gatlin

Concentrations of total filtered and unfiltered phosphorus have followed a similar pattern as previously described. Currently (PSIII) total filtered and unfiltered phosphorus concentrations are below baseline values (Table 6).

Organic nitrogen concentrations have increased slightly throughout the project. Ammonia concentrations have increased above baseline during the second and third poststocking time intervals.

Figure 10 shows chlorophyll a and carotenoids decreasing through this poststocking time frame (PSIII). However, these parameters have equaled or slightly exceeded baseline data by comparison.

Hardness and total solids measurements are higher in Lake Gatlin than the other pools. Figure 11 shows that hardness concentrations have remained relatively unchanged, while total solids have varied slightly.

Conclusions

After stocking of the white amur, phosphorus concentrations have decreased while ammonia concentrations have increased throughout the water column.

These changes may be attributable to activities of the white amur. Further slight increases in phytoplankton standing crop (as measured by chlorophyll a and carotenoids) may be related to the observed changes in nutrient (phosphorus and ammonia) concentrations. Hardness and total solids concentrations have remained relatively constant throughout the project. It appears that the introduction of the white amur has not caused water quality to be degraded in Lake Conway.

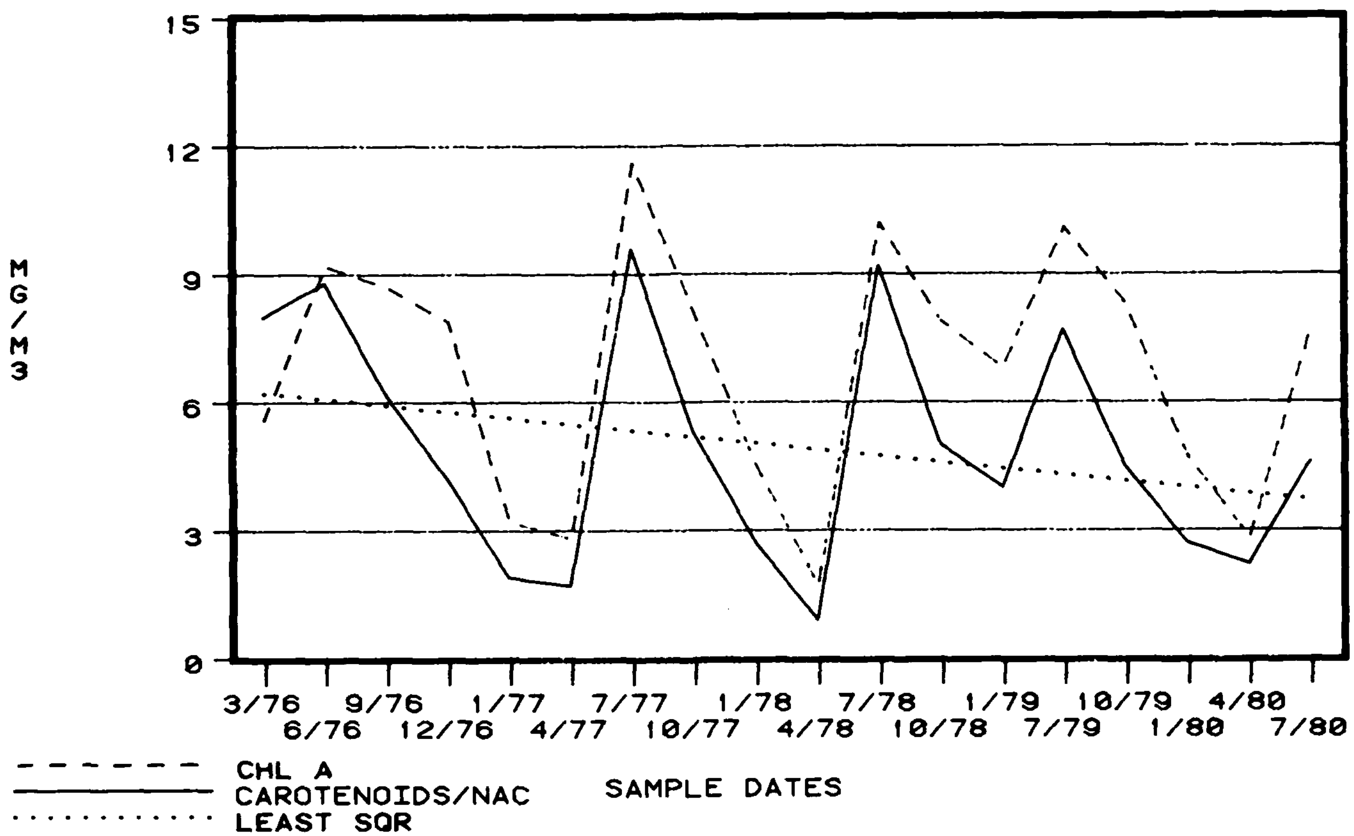

Figure 8. LSOMT West Pool-Mid CHL A and NAC surface samples

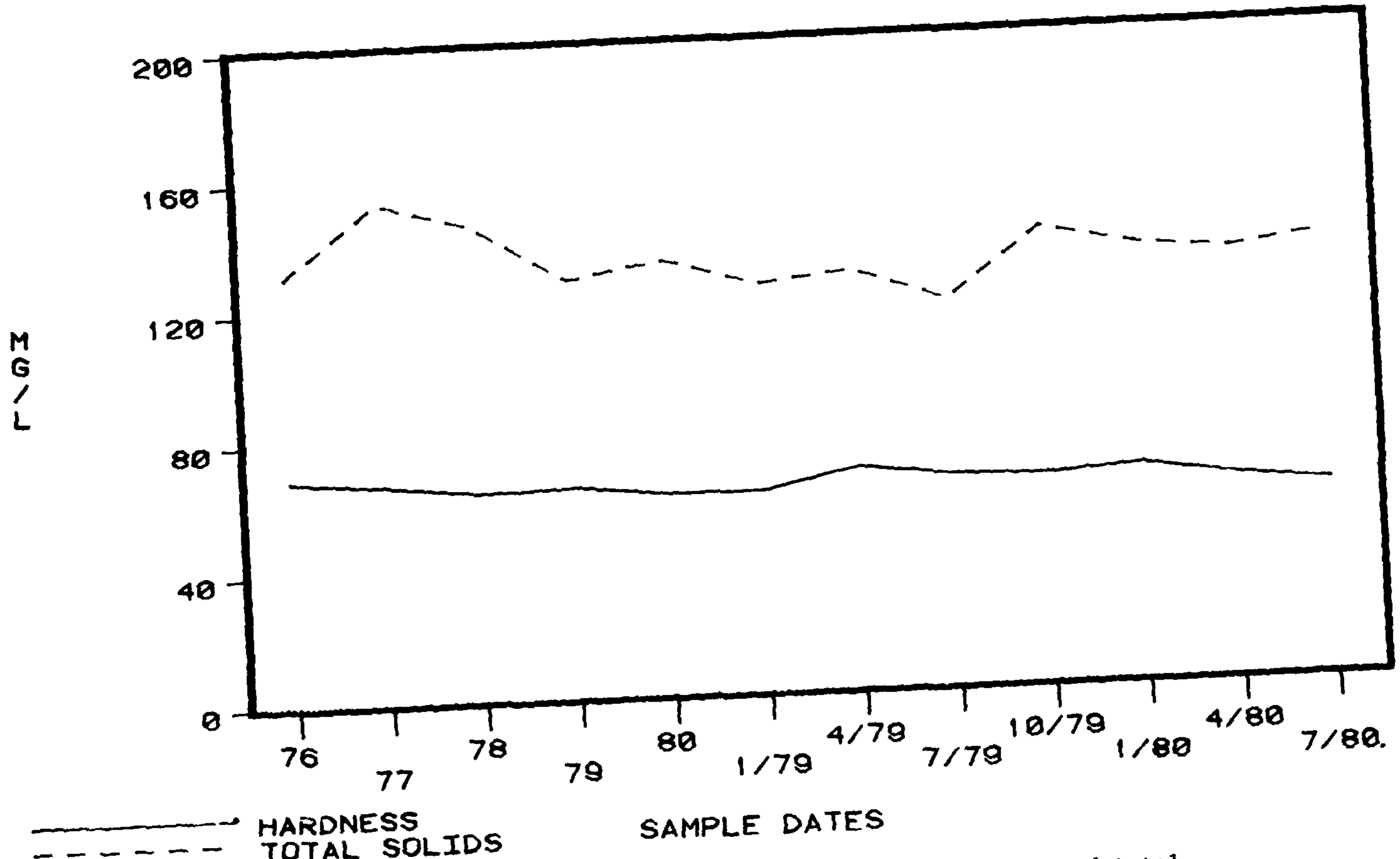

Figure 9. LSOMT West Pool-Mid (yearly averages of hardness and total solids concentration followed by quarterly results)

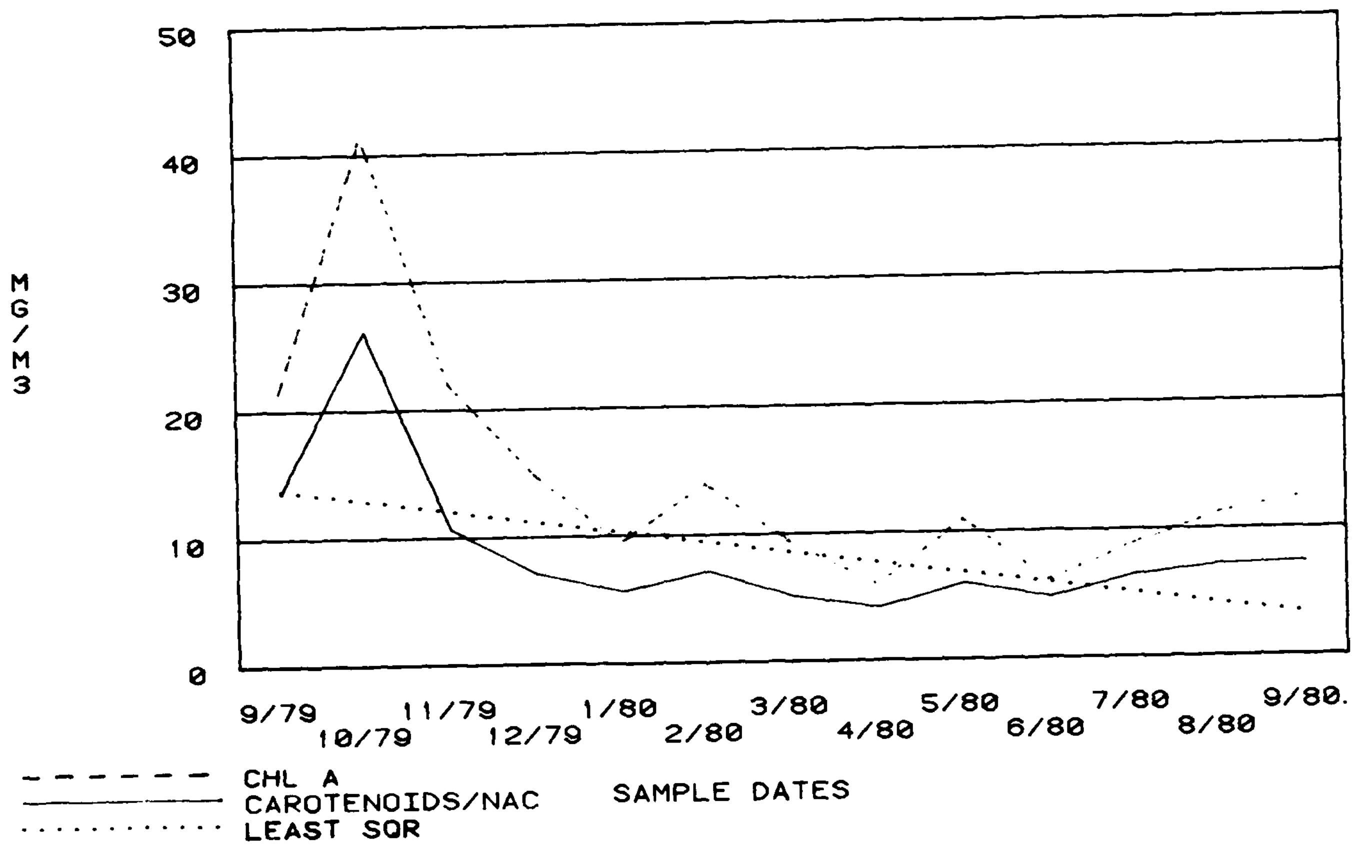

Figure 10. LSOMT Lake Gatlin CHL A and NAC surface-bottom average

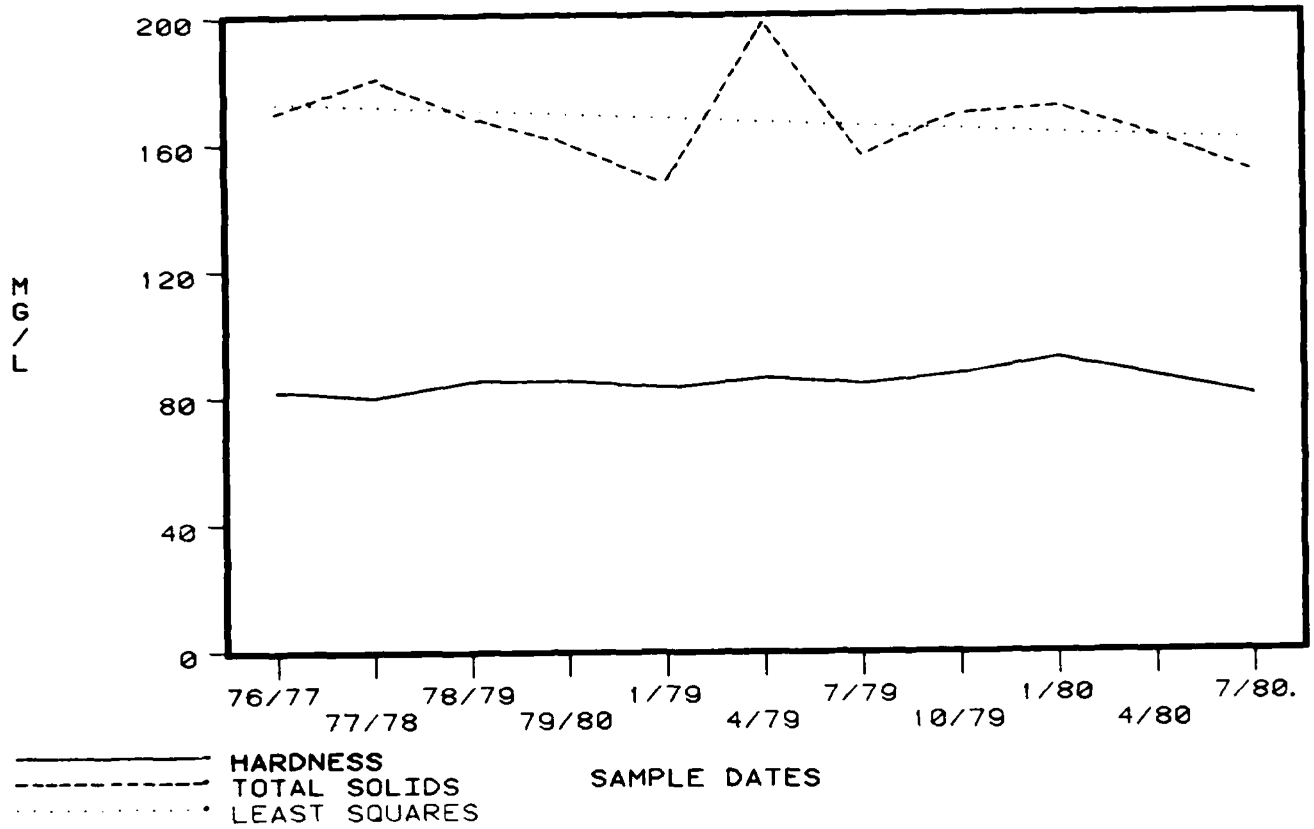

Figure 11. LSOMT Lake Gatlin (yearly averages of hardness and total solids concentration followed by quarterly results)

Table 1

Water Quality Parameters

Chemical and Biological Analysis

Dissolved oxygen	Solids, volatile
Biochemical oxygen demand	Turbidity
Chemical oxygen demand	Sodium
Hardness	Calcium
pH	Magnesium
Alkalinity	Potassium
Acidity	Iron
Phosphorus, total	Copper
Phosphorus, ortho	Lead
Phosphorus, total unfilterable	Chlorophyll *a*
Nitrate-nitrite	Chlorophyll *b*
Ammonia	Chlorophyll *c*
Organic nitrogen	Ratio, chlorophyll *b:a*
Chlorides	Functional, chlorophyll *a*
Solids, total	Nonfunctional, chlorophyll *a*
Solids, suspended	Carotenoids, nonastacians

In Situ Measurements

Temperature	Oxidation reduction potential
Specific conductance	Dissolved oxygen
Secchi disk	Primary productivity
pH	

Table 2

Data Analysis, South Pool

	1/76-8/77(B)		9/77-8/78(PSI)		9/78-8/79(PSII)		9/79-8/80(PSIII)	
	X	SD	X	SD	X	SD	X	SD
400117								
TFP, mg/ℓ	0.017	0.007	0.011	0.001	0.010	0.000	0.010	0.000
TUP, mg/ℓ	0.025	0.009	0.013	0.003	0.011	0.003	0.015	0.009
Org-N, mg/ℓ	0.49	0.07	0.46	0.11	0.51	0.17	0.48	0.13
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.090	0.03	0.084	0.05
K, mg/ℓ	4.0	0.3	4.4	0.1	4.7	3.0	4.9	0.3
NAC, mg/m^3	3.1	2.8	1.6	0.8	2.5	1.3	3.33	1.9
SD, m	2.9	0.7	3.5	0.3	2.5	0.5	2.5	0.6
282197								
TFP, mg/ℓ	0.016	0.007	0.011	0.001	0.010	0.000	0.010	0.000
TUP, mg/ℓ	0.023	0.008	0.013	0.003	0.011	0.003	0.014	0.005
Org-N, mg/ℓ	0.49	0.07	0.48	0.10	0.53	0.10	0.58	0.25
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.09	0.03	0.07	0.04
K, mg/ℓ	4.0	0.3	4.3	0.1	4.7	0.3	4.8	0.22
NAC, mg/m^3	3.0	2.7	1.5	0.7	2.5	1.4	3.9	1.7
SD, m	3.3	0.1	3.6	1.2	2.6	0.5	2.4	1.0

Table 3

Data Analysis, Middle Pool

	1/76-8/77		9/77-8/78		9/78-8/79		9/79-8/80	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
210302								
TFP, mg/ℓ	0.016	0.007	0.011	0.002	<0.010	0.000	<0.010	0.000
TUP, mg/ℓ	0.022	0.007	0.015	0.004	0.013	0.004	0.015	0.009
Org-N, mg/ℓ	0.43	0.08	0.48	0.09	0.54	0.09	0.52	0.16
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.08	0.03	0.08	0.03
K, mg/ℓ	3.5	0.2	4.0	0.1	4.5	0.2	4.3	0.9
NAC, mg/m^3	3.2	2.6	3.0	0.4	3.2	1.5	4.4	1.3
SD, m	2.9	0.6	3.0	0.4	2.5	0.5	2.7	0.4
415312								
TFP, mg/ℓ	0.017	0.007	0.012	0.006	0.010	0.000	0.011	0.002
TUP, mg/ℓ	0.024	0.009	0.015	0.004	0.013	0.004	0.014	0.009
Org-N, mg/ℓ	0.43	0.08	0.48	0.09	0.52	0.11	0.56	0.18
NA_3-N, mg/ℓ	<0.050	--	<0.050	--	0.08	0.03	0.07	0.02
K, mg/ℓ	3.5	0.2	4.0	0.2	4.4	0.2	4.5	0.2
NAC, mg/m^3	3.4	2.4	3.1	1.9	3.2	1.5	3.8	0.9
SD, m	3.1	0.8	3.6	1.0	2.7	0.6	2.7	0.9
332385								
TFP, mg/ℓ	0.015	0.004	0.012	0.004	0.010	0.000	0.010	0.000
TUP, mg/ℓ	0.022	0.008	0.015	0.004	0.012	0.006	0.013	0.005
Org-N, mg/ℓ	0.44	0.08	0.53	0.16	0.53	0.18	0.51	0.07
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.09	0.06	0.06	0.02
K, mg/ℓ	3.5	0.3	4.1	0.3	4.4	0.2	4.5	0.2
NAC, mg/m^3	3.2	2.7	2.8	1.7	3.0	1.4	3.91	1.14
SD, m	NA		NA		NA		NA	

Table 4

Data Analysis, East Pool

	1/76-8/77(B)		9/77-8/78(PSI)		9/78-8/79(PSII)		9/79-8/80(PSIII)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
				380455				
TFP, mg/ℓ	0.018	0.007	0.015	0.004	0.010	0.000	0.013	0.005
TUP, mg/ℓ	0.027	0.012	0.019	0.006	0.012	0.005	0.016	0.005
Org-N, mg/ℓ	0.54	0.04	0.50	0.09	0.56	0.22	0.45	0.09
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.08	0.03	0.07	0.05
K, mg/ℓ	4.1	0.3	4.4	0.2	4.7	0.4	4.6	0.2
NAC, mg/m^3	4.6	2.6	2.3	1.0	4.8	1.5	3.52	1.23
SD, m	NA		NA		NA		NA	
				415532				
TFP, mg/ℓ	0.017	0.007	0.012	0.002	0.010	0.000	0.011	0.003
TUP, mg/ℓ	0.025	0.011	0.019	0.005	0.017	0.007	0.016	0.005
Org-N, mg/ℓ	0.54	0.04	0.50	0.09	0.53	0.21	0.51	0.12
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.07	0.03	0.055	0.02
K, mg/ℓ	4.1	0.3	4.4	0.2	4.7	0.4	4.7	0.2
NAC, mg/m^3	4.6	2.6	3.1	1.8	5.2	1.2	4.17	1.29
SD, m	2.4	0.5	2.8	0.4	2.4	0.4	2.4	0.6

Table 5

Data Analysis, West Pool

	1/76-8/77(B)		9/77-8/78(PSI)		9/78-8/79(PSII)		9/79-8/80(PSIII)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
				212495				
TFP, mg/ℓ	0.018	0.007	0.011	0.001	<0.010	0.000	<0.010	0.000
TUP, mg/ℓ	0.026	0.008	0.016	0.004	0.015	0.007	0.013	0.005
Org-N, mg/ℓ	0.54	0.05	0.50	0.1	0.53	0.17	0.50	0.17
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.08	0.05	0.07	0.03
K, mg/ℓ	4.2	0.3	4.4	0.2	4.8	0.4	4.7	0.3
NAC, mg/m^3	5.4	3.3	3.4	2.2	5.3	1.2	4.16	1.58
SD, m	2.5	0.8	2.8	0.5	2.0	0.3	2.3	0.6
				195382				
TFP, mg/ℓ	0.017	0.006	0.013	0.004	<0.010	0.000	<0.010	0.000
TUP, mg/ℓ	0.025	0.007	0.015	0.004	0.015	0.007	0.013	0.004
Org-N, mg/ℓ	0.53	0.06	0.49	0.12	0.53	0.13	0.51	0.154
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.09	0.05	0.06	0.02
K, mg/ℓ	4.3	0.2	4.4	0.1	4.9	0.3	4.6	0.2
NAC, mg/m^3	5.2	3.6	3.2	2.1	5.1	1.3	4.0	1.5
SD, m	2.3	0.5	2.4	0.2	2.0	0.2	2.3	0.4
				157435				
TFP, mg/ℓ	0.017	0.005	0.012	0.002	<0.010	0.000	<0.010	0.000
TUP, mg/ℓ	0.027	0.008	0.015	0.004	0.015	0.007	0.015	0.008
Org-N, mg/ℓ	0.54	0.04	0.48	0.10	0.53	0.12	0.57	0.22
NH_3-N, mg/ℓ	<0.050	--	<0.050	--	0.10	0.06	0.06	0.02
K, mg/ℓ	4.3	0.3	4.4	0.0	4.9	0.3	4.6	0.2
NAC, mg/m^3	5.4	3.5	3.1	2.2	5.2	1.3	3.93	1.43
SD, m	2.4	0.9	3.0	0.8	2.0	0.4	2.5	0.8

Table 6

Data Analysis, Lake Gatlin

	1/76-8/77(B)		9/77-8/78(PSI)		9/78-8/79(PSII)		9/79-8/80(PSIII)	
	X	SD	X	SD	X	SD	X	SD
				132497				
TFP, mg/ℓ	0.018	0.006	0.013	0.003	0.010	0.000	0.011	0.004
TUP, mg/ℓ	0.028	0.009	0.019	0.007	0.015	0.006	0.020	0.001
Org-N, mg/ℓ	0.56	0.13	0.62	0.19	0.65	0.14	0.74	0.27
NH_3-N, mg/ℓ	0.050	0.000	0.009	0.12	0.09	0.04	0.07	0.03
K, mg/ℓ	5.3	0.3	5.5	0.2	5.6	0.3	5.5	0.24
NAC, mg/m^3	6.5	4.8	8.8	7.0	8.7	6.1	9.1	7.0
SD, m	2.1	0.7	2.0	0.9	1.8	0.8	1.8	0.6

LARGE-SCALE OPERATIONS MANAGEMENT TESTS

The Plankton and Benthic Invertebrate Response

by

Thomas L. Crisman* and Floor M. Kooijman*

Introduction

Submersed aquatic weeds including the exotic species *Hydrilla verticillata* pose a serious management problem for freshwater habitats of the southeastern United States. In searching for effective biological control techniques for weed management, WES funded an ecosystem study beginning in 1976 at Lake Conway, Florida, to evaluate the response of native fauna and flora to the introduction of the herbivorous exotic fish, the white amur (*Ctenopharyngodon idella*). The Department of Environmental Engineering Sciences of the University of Florida has been responsible for monitoring periphyton, phytoplankton, zooplankton, and benthic invertebrates in the five pools of the Conway system during both the prestocking (May 1976-August 1977) and poststocking (September 1977-September 1980) periods. The following report presents the preliminary analysis of the data from the first 4 years of monitoring.

Secchi Disk Transparency

In systems such as Lake Conway that are little influenced by inorganic turbidity, water clarity, as measured by a Secchi disk, provides a semiquantitative estimate of algal density in the water column. Secchi disk transparency was consistently maximal during winter and early spring, the period of lowest algal biomass, and minimal during summer associated with a seasonal phytoplankton expansion (Figure 1). The second and third poststocking years differed from the two previous years by the absence of a pronounced increase in water transparency during winter and spring. Instead, Secchi disk transparency remained relatively constant throughout the year and approximated the summertime minima recorded during the prestocking and first poststocking years.

Phytoplankton

Algal concentrations in the Conway system generally were maximal

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Figure 1. Secchi disk transparency in the Middle Pool of Lake Conway during the prestocking (May 1976-August 1977) and poststocking (September 1977-June 1980) periods

during summer and minimal during late winter and early spring, thus paralleling changes in Secchi disk transparency (Figure 2). The post-stocking period differed from the prestocking period by the presence of substantially elevated algal concentrations for all seasons as well as more pronounced between-season population fluctuations. Winter minima during the poststocking period generally exceeded summer maxima of the prestocking period.

Diatoms, cryptophytes, and green algae were important seasonal dominants during the prestocking and the first half of the first poststocking year with blue-greens becoming a dominant element only during late spring and summer-fall (Figure 3). During the last 2.5 years of monitoring, diatoms, cryptophytes, and green algae were reduced to only minor importance, and blue-green algae dominated (>75 percent) phytoplankton assemblages during all seasons. The notable exception to this trend occurred during late winter and spring of 1980 when green algae became dominant for a short period. The increased importance of blue-green algae during the poststocking period was accompanied by over a 30 percent reduction in the total number of phytoplankton species encountered in the lake system.

Zooplankton

Zooplankton populations during the prestocking period were characterized by a late spring maximum and a midsummer minimum, each of rather short duration (Figure 4). Although this seasonal population trend was also apparent during the poststocking period, the duration of both the spring maximum and the midsummer minimum was temporally expanded. The presence of a pronounced fall zooplankton peak during the first post-stocking year and the general temporal expansion of the spring peak during the poststocking period are attributed to an increase in food availability (phytoplankton). The prolonged summer minima are likely associated with a temporal expansion of the period of hypolimnetic anoxia during the period of midsummer thermal stratification resulting from elevated algal populations in the epilimnion and their subsequent decomposition in profundal waters. Zooplankton populations would decline during such periods of midsummer hypolimnetic deoxygenation because they would be confined to the epilimnion where midsummer temperatures may be physiologically stressful (cladocerans) and where macrozooplankton (copepods, cladocerans) would be increasingly susceptible to fish predation.

Cladocerans and copepods dominated the zooplankton assemblages of the Conway system during all seasons except summer when cladocerans were replaced by rotifers. No major differences in the overall importance of these three groups could be associated with the introduction of the white amur.

Benthic Invertebrates

During both the prestocking and poststocking periods, both the number of species and the abundance of benthic invertebrates in all

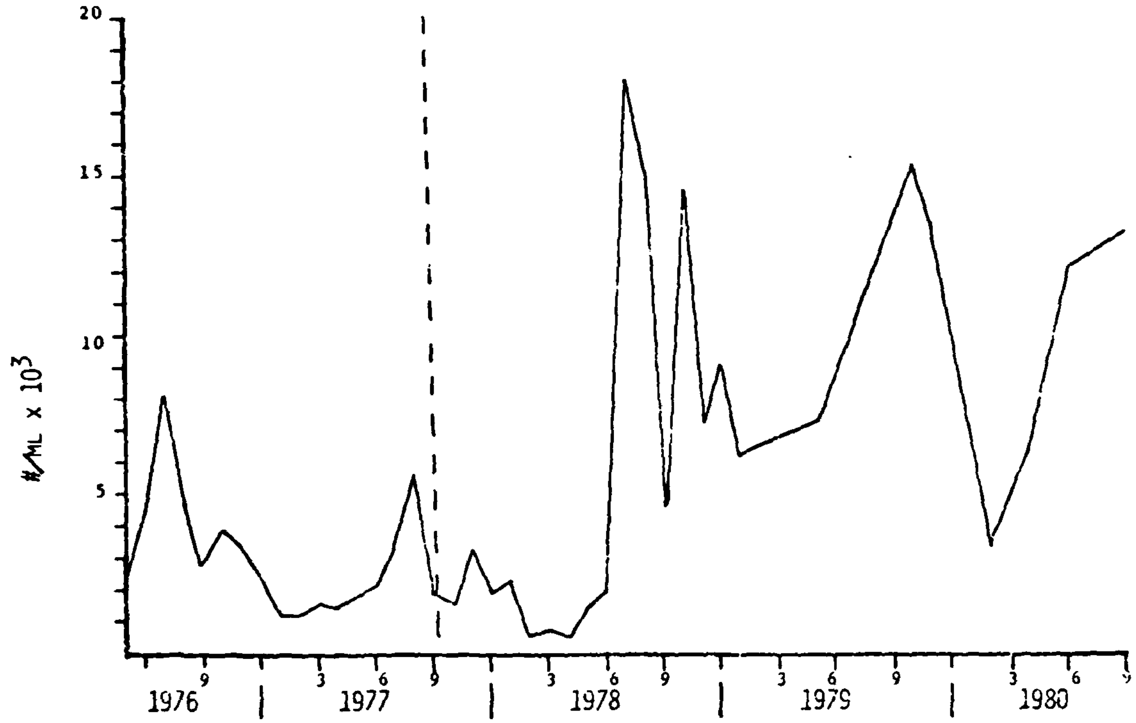

Figure 2. Phytoplankton abundance in the Middle Pool of Lake Conway during the prestocking (July 1976-August 1977) and poststocking (September 1977-September 1980) periods

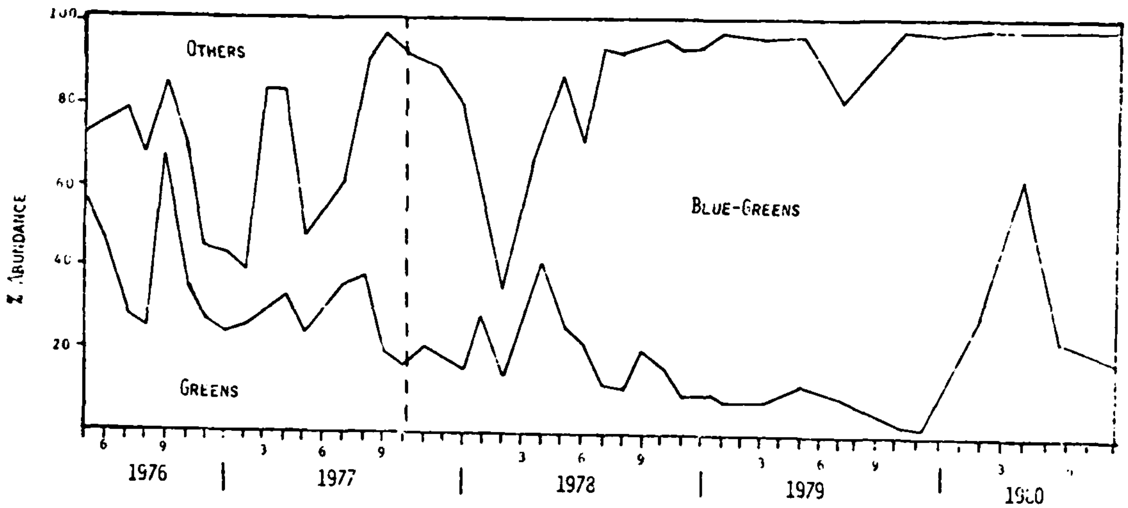

Figure 3. Phytoplankton composition in the Middle Pool of Lake Conway during the prestocking (May 1976-August 1977) and poststocking (September 1977-August 1980) periods

Figure 4. Zooplankton abundance in the Middle Pool of Lake Conway during the prestocking (May 1976-August 1977) and poststocking (September 1977-September 1980) periods

pools of the Conway system were greater at shallow (<3 m) than at deep (>3 m) stations (Figure 5). Abundance at both stations was maximal during winter and minimal during summer. Neither the density of individuals nor the number of species encountered differed markedly between the prestocking and poststocking periods.

Finally, the relative importance of the major benthic invertebrate groups did not change as a function of white amur introduction. Although minor seasonal differences were noted, shallow stations were dominated throughout the year by oligochaetes and chironomids, while these two groups shared dominance at deep water stations with the phantom midge, *Chaoborus*. *Chaoborus* is not entirely benthic in its behavior but migrates vertically through the water column to feed on zooplankton in the surface waters at night.

Conclusions

Phytoplankton and their principal grazers, zooplankton, have displayed the greatest biotic response to the introduction of white amur into Lake Conway, Florida. Algal abundance increased markedly during the poststocking period, and the seasonal importance of diatoms, cryptophytes, and green algae evident during the prestocking period was greatly diminished during the poststocking period as blue-green algae dominated phytoplankton assemblages throughout the year. Zooplankton populations also increased during the poststocking period, and seasonal maxima and minima were temporally extended relative to the prestocking period. Unlike that observed for phytoplankton, no major shift in zooplankton dominance accompanied white amur introduction.

The biotic response to fish stocking was least pronounced with the benthic invertebrates. Shallow stations (<3 m) consistently were characterized by higher benthos densities than deep (>3 m) stations throughout the investigation, but no major population or compositional changes can be associated with white amur introduction. The greater density and diversity of the shallow relative to deep stations are attributed to greater habitat diversity (macrophytes, substrate heterogeneity) and less pronounced oxygen stress at the former stations.

In summary, it is likely that the plankton response to white amur introduction results from aquatic weed removal and associated habitat alteration and changing patterns of nutrient cycling rather than the direct feeding activity of the fish itself. The observed increase in plankton biomass may be of short temporal duration and likely will stabilize at lower levels associated with attrition of white amur populations and the reestablishment of aquatic weeds.

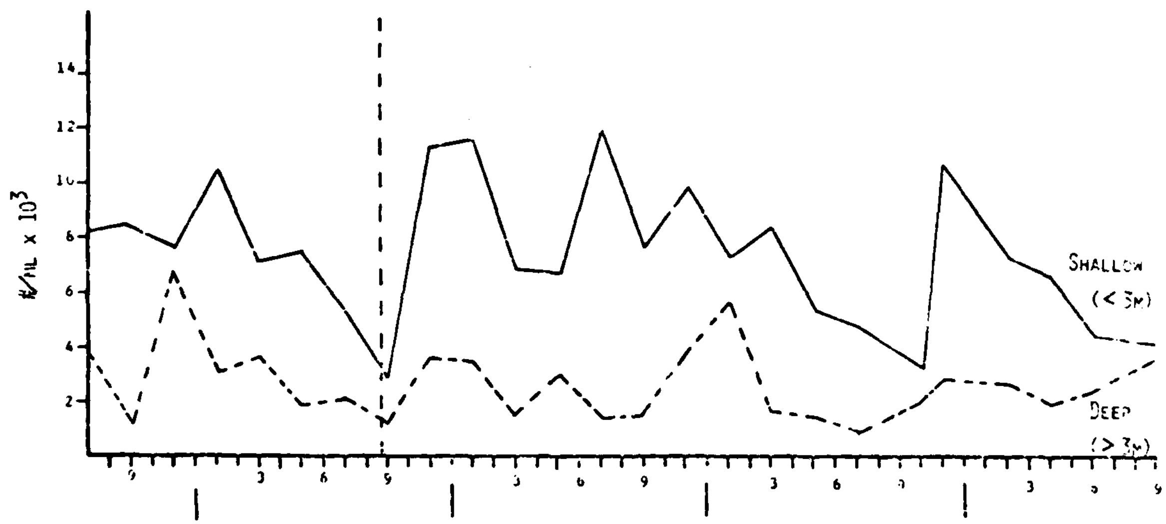

Figure 5. Mean abundance of benthic invertebrates at shallow (<3 m) and deep (>3 m) stations of the Conway system during the prestocking (July 1976-August 1977) and poststocking (September 1977-September 1980) periods

LARGE-SCALE OPERATIONS MANAGEMENT TEST

The Herpetofauna of Lake Conway

by

J. Steve Godley,* G. Thomas Bancroft,* and Roy W. McDiarmid**

As part of the Lake Conway LSOMT, the University of South Florida has been investigating the possible effects of the white amur on the native amphibians and reptiles of Lake Conway. This paper provides a preliminary summary of changes observed in the herpetofaunal populations during the 3-year study (June 1977-September 1980).

Details of the herpetofaunal sampling program on Lake Conway are presented in Godley, Bancroft, and McDiarmid (1981),+ and only a brief summary is given here. Amphibians and reptiles were monitored primarily by bimonthly funnel trapping and bimonthly nocturnal censusing (=herp-patrol) of five permanent shoreline sites (Figure 1). All individuals captured on these sites were measured, weighed, permanently marked, and released at the capture point for long-term mark and recapture population studies. Destructive samples for stomach and reproductive analysis of selected species were taken monthly from distant areas of similar habitat within the lake system.

A total of 12,927 individuals representing 12 species of amphibians and 17 species of reptiles were observed or captured on Lake Conway during the 3-year study. Figure 2 shows the cumulative number of species as a function of the cumulative number of individuals recorded on Lake Conway. A total of 27 species were obtained in the first year, two additional species in the second year, and no new species in the third year. Based on this sample, there are four species of salamanders, eight anurans, one crocodilian, nine turtles, and seven snakes inhabiting the Lake Conway complex (Table 1).

Tables 2-6 summarize for each permanent shoreline site on Lake Conway yearly changes in the relative abundance of herpetofaunal species as determined by the two major sampling methods: herp-patrol (mean number/hr) and funnel trapping (mean number/100 trap days). Table 7 provides the same information for all permanent sites combined. Between-year differences in relative densities within permanent sites were

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* University of South Florida, Tampa, Florida.

** U. S. Fish and Wildlife Service, National Museum of National History, Washington, D. C.

\+ Godley, J. S., Bancroft, G. T. and McDiarmid, R. W. 1981. "Large-Scale Operations Management Test of Use of the White Amur for Control of Aquatic Plants; Report 1, Baseline Studies; Volume V: The Herpetofauna of Lake Conway, Florida" (in press), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

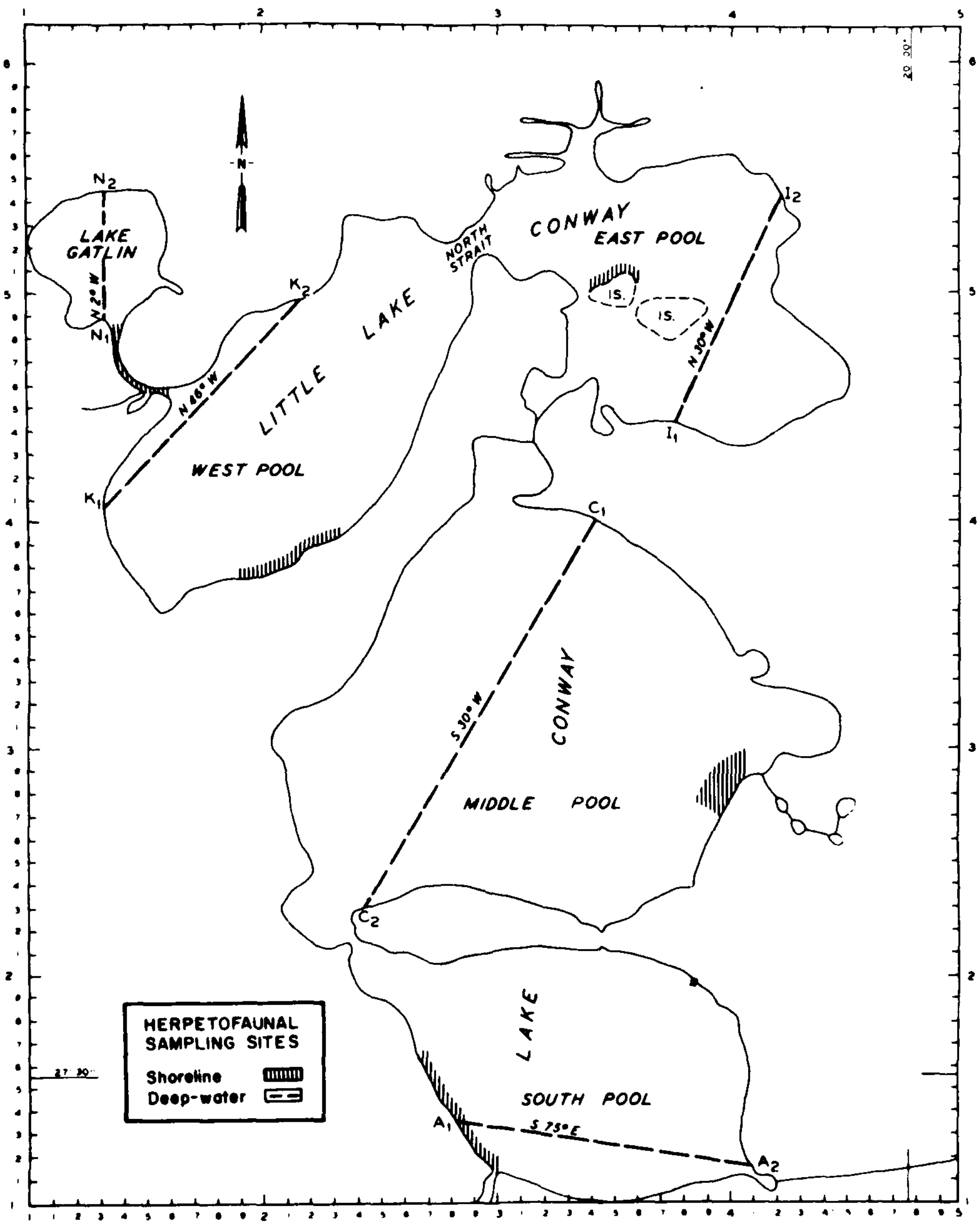

Figure 1. Permanent sampling sites for amphibians and reptiles on Lake Conway

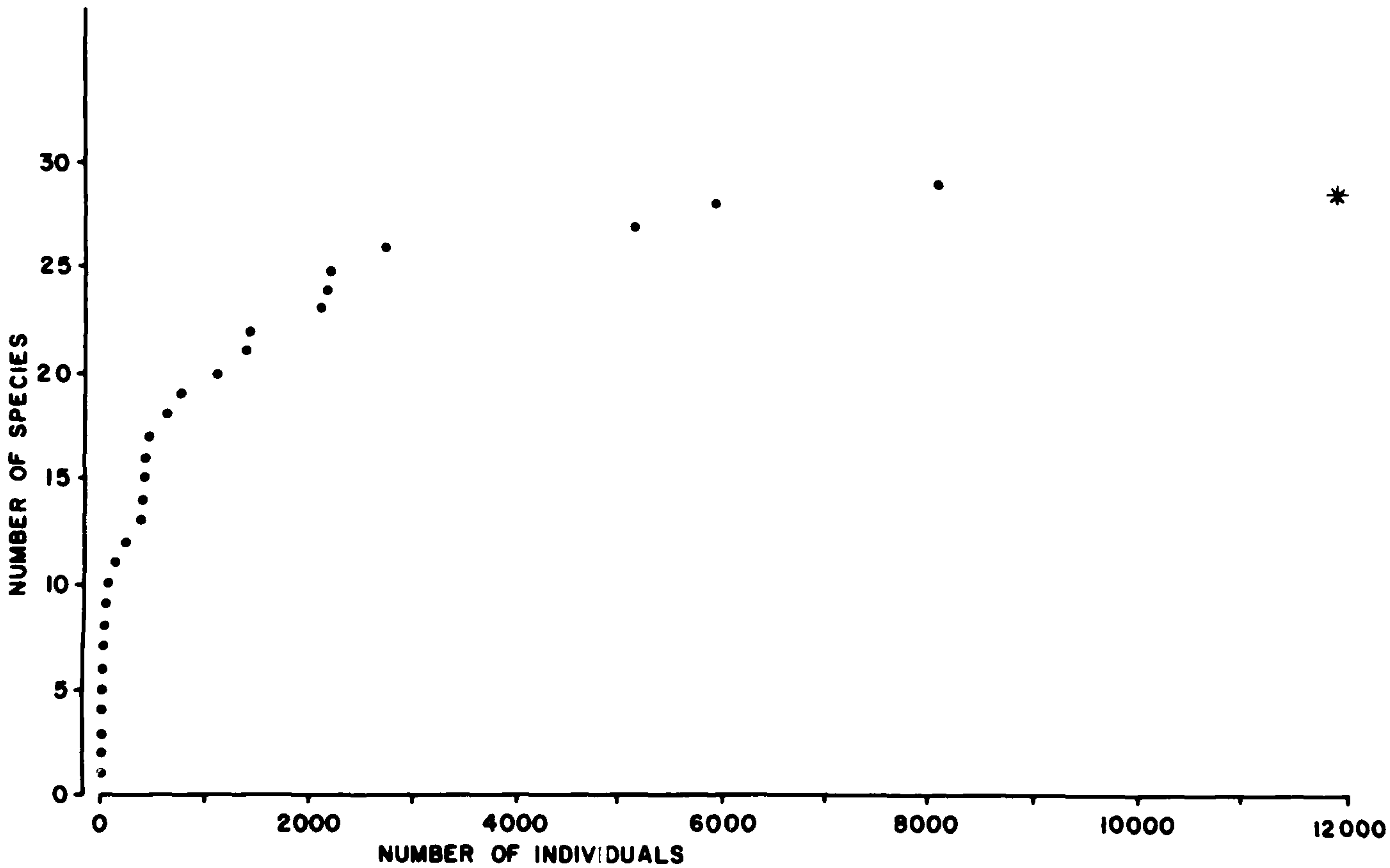

Figure 2. The cumulative number of amphibians and reptile species as a function of the cumulative number of individuals recorded on Lake Conway. Asterisk indicates last individual collected during the 3-year study period

tested by using the chi-square approximation of the nonparametric Krushal Wallis extension of the Mann-Whitney U-test (Barr et al. 1979)* for herp-patrol trips, and the difference among proportions test (Freund 1973)** for funnel trapping. If significant between-year differences ($p < 0.5$) were found, pair-wise comparisons of years were performed using the Mann-Whitney U-test (herp-patrols) or the difference among proportions test (funnel traps). Because the same data were analyzed for this second test, the alpha level of significance was increased to $p < 0.025$.

In general, the sum ranks test used for herp-patrol comparisons is less robust than the chi-square test used for funnel trap analysis. This means that yearly trends seen in a number of species on herp-patrols probably are real, but more difficult to demonstrate statistically than trends observed in funnel-trapped species.

Depending upon the pool, three to five species show significant yearly changes in relative density (Tables 2-6). This species list includes two salamanders, three frogs, four turtles, and one snake. Seven of these species show significant yearly differences only in funnel traps, one species only on herp-patrols, and two species vary significantly by both sampling methods. When results from all pools are combined (Table 7), eight species show significant between-year differences in relative density, including two species of salamanders, two frogs, three turtles, and one snake. Yearly changes in abundance were detected in all of these species by funnel trap analysis; one of these species also varied significantly on herp-patrols.

The two salamander species that varied in relative density (*Amphiuma means* and *Siren lacertina*) were taken primarily in funnel traps and generally showed decreasing populations in most pools during the study (Tables 2-6). In both species the causes of population declines appear to be complex and vary with the pool. In two pools (South and Middle) declines in capture success were correlated with habitat destruction by man; in two other pools (East and West) river otter (*Lutra canadensis*) habitually raided the funnel traps and may have eaten a significant proportion of both salamander populations. Survivorship in neither species appears to be affected by the marking techniques, but evidence indicates that at least one salamander species (*A. means*) becomes trap-shy with repeated captures.

A number of frog species showed increases in the mean number of males heard calling on herp-patrols, but most of these increases were not statistically significant (Tables 2-7). Two species did exhibi significant yearly increases in the number of calling males on permanent sites (*Rana grylio* in Gatlin Canal and *R. utricularia* in Middle Pool). Funnel trap analysis showed yearly fluctuations in the density of adults

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* Barr, A. J. et al. 1979. SAS User's Guide, 1979 ed., SAS Institute, Raleigh, North Carolina.

** Freund, J. E. 1973. Modern Elementary Statistics, Prentice-Hall, Englewood Cliffs, New Jersey.

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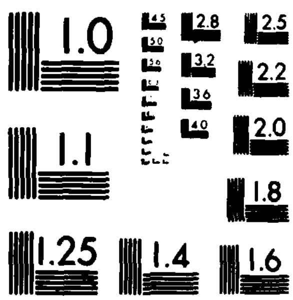

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

and/or tadpoles of three species (*Hyla cinerea, R. grylio, R. utricularia*). At present the causes of the increases in breeding frog populations are unknown but may represent improved survivorship or breeding success.

Several species of reptiles varied in relative abundance during the study (Tables 2-7). Three turtle species decreased significantly in some pools (*Kinosternon subrubrum* in South Pool, *Sternotherus odoratus* in South Pool and Gatlin Canal, *Chrysemys floridana* in South and Middle Pools) and one species (*Chelydra serpentina* in Gatlin Canal) apparently fluctuated in abundance. The only snake showing changes in density was *Nerodia cyclopion*, which decreased significantly in South, Middle, and East Pools. Again, the apparent causes of these population changes are varied and complex. For example, habitat destruction by man probably decreased some turtle and snake populations in South and Middle Pools, but cannot explain changes in the same species in other pools.

Changes in the relative density of a number of species of amphibians and reptiles are correlated with decreases in plant biomass as a result of white amur feeding activity. However, many changes in herpetofaunal populations also are correlated with other confounding factors (e.g., habitat destruction, trap predation by otters, etc.). At present it is not clear if white amur are causally related to the observed changes in herpetofauna populations. Further analysis of the data over the next several months will specifically address this question.

Table 1

Checklist of amphibians and reptiles known from the Lake Conway system

Scientific Name	Common Name
AMPHIBIA	
CAUDATA	
SIRENIDAE	
Pseudobranchus striatus	Dwarf siren
Siren lacertina	Greater siren
AMPHIUMIDAE	
Amphiuma means	Two-toed amphiuma
PLETHODONTIDAE	
Eurycea quadridigitata	Dwarf salamander
ANURA	
BUFONIDAE	
Bufo terrestris	Southern toad
MICROHYLIDAE	
Gastrophryne carolinensis	Eastern narrow-mouthed toad
RANIDAE	
Rana grylio	Pig frog
Rana utricularia	Southern leopard frog
HYLIDAE	
Acris gryllus	Florida cricket frog
Hyla cinerea	Green treefrog
Hyla femoralis	Pinewoods treefrog
Hyla squirella	Squirrel treefrog

(Continued)

Table 1 (Concluded)

Scientific Name	Common Name
REPTILIA	
CROCODILIA	
CROCODILIDAE	
Alligator mississippiensis	American alligator
TESTUDINATA	
CHELYDRIDAE	
Chelydra serpentina	Florida snapping turtle
KINOSTERNIDAE	
Kinosternon bauri	Striped mud turtle
Kinsoternon subrubrum	Eastern mud turtle
Sternotherus odoratus	Stinkpot
EMYDIDAE	
Chrysemys floridana	Peninsular cooter
Chrysemys nelsoni	Florida red-bellied turtle
Chrysemys scripta	Red-eared turtle
Deirochelys reticularia	Chicken turtle
TRIONYCHIDAE	
Trionyx ferox	Florida softshell
SQUAMATA	
COLUBRIDAE	
Coluber constrictor	Black racer
Farancia abacura	Mud snake
Nerodia cyclopion	Green water snake
Nerodia fasciata	Florida water snake
Regina alleni	Striped swamp snake
Thamnophis sauritus	Peninsula ribbon snake
Thamnophis sirtalis	Eastern garter snake

Table 2

The distribution and relative density of amphibians and reptiles on the South Pool permanent shoreline site during the three-year study. Yearly site summaries include the number of species by major taxonomic unit (parentheses), the total number of individuals of a species seen or captured by all methods (raw values), and their mean relative density as estimated by two methods: herp-patrol (H.P. = mean number/hour) and funnel traps (F.T. = mean number/100 trap days). Chi-square values compare all three years (* = $P<.05$, ** = $P<.01$, NS = not significant). If significant between-year differences ($P<.05$) were detected, pair-wise comparisons of years were performed. Yearly means with the same letter *indicate no significant difference* between those years ($P<.025$). See text for details

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Total herp-patrol hours	32.15	17.35	14.43	63.93	
Total trap days	928	1171	1162	3261	
AMPHIBIA	(8)	(8)	(6)	(8)	
CAUDATA	(2)	(2)	(1)	(2)	
Amphiuma means	21	3	0	24	
H.P.					
F.T.	2.26	0.09_A	0.00_A	0.70	46.739 **

(Continued)

(Sheet 1 of 5)

Table 2 (Continued)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
Amphiuma means (eggs)	0	2	0	2		
H.P.						
F.T.						
Siren lacertina	1	6	3	10		
H.P.	0.00	0.13	0.00	0.04	0.350	NS
F.T.	0.00	0.28	0.00	0.09	5.860	NS
ANURA	(6)	(6)	(5)	(6)		
Acris gryllus (adults)	503	133	132	768		
H.P.	16.17	15.89	18.06	16.72	0.030	NS
F.T.						
Bufo terrestris (adults)	8	1	2	11		
H.P.	0.28	0.09	0.26	0.22	0.079	NS
F.T.						
Gastrophryne carolinensis (adults)	5	3	1	9		
H.P.	0.00	0.36	0.14	0.16	0.596	NS
F.T.						
Hyla cinerea (adults)	37	34	11	82		
H.P.	1.09	3.74	1.09	1.95	1.992	NS
F.T.						
Hyla cinerea (larvae)	1	0	0	1		
H.P.						
F.T.	0.11	0.00	0.00	0.03	2.407	NS

(Continued)

(Sheet 2 of 5)

Table 2 (Continued)

	Study Year 1977-78	1978-79	1979-80	Total	χ^2
Hyla squirella (adults)	7	10	0	17	
H.P.	0.10	0.53	0.00	0.21	
F.T.					
Rana utricularia (adults)	30	44	16	90	
H.P.	1.31	2.27	2.21	1.92	0.126 NS
F.T.					
Rana utricularia (larvae)	1	4	0	5	
H.P.					
F.T.	0.11	0.37	0.00	0.16	5.134 NS
Rana utricularia (eggs)	1	0	0	1	
H.P.					
F.T.					
REPTILIA	(12)	(12)	(9)	(14)	
CROCODILIA	(0)	(0)	(0)	(0)	
TESTUDINATA	(6)	(8)	(7)	(8)	
Chelydra serpentina	0	1	0	1	
H.P.					
F.T.					
Chrysemys floridana	93	10	4	107	
H.P.	1.51	0.38_A	0.14_A	0.68	20.593 **
F.T.					

(Continued)

(Sheet 3 of 5)

Table 2 (Continued)

	Study Year 1977-78	1978-79	1979-80	Total	χ^2	
Chrysemys nelsoni	12	2	4	18		
H.P.	0.14	0.07	0.20	0.14	0.785	NS
F.T.	0.11	0.00	0.00	0.03	2.407	NS
Chrysemys scripta	0	2	0	2		
H.P.						
F.T.	0.00	0.09	0.00	0.03	1.952	NS
Kinosternon bauri	6	1	2	9		
H.P.	0.03	0.00	0.00	0.01		
F.T.	0.11	0.00	0.00	0.03	2.407	NS
Kinosternon subrubrum	38	4	3	45		
H.P.	0.14	0.14	0.11	0.13	0.187	NS
F.T.	2.59	0.09_A	0.00_A	0.79	54.025	**
Sternotherus odoratus	339	115	113	567		
H.P.	6.22	5.45	6.30	6.00	0.912	NS
F.T.	1.19	0.28_A	0.00_A	0.44	17.414	**
Sternotherus odoratus (eggs)	0	2	0	2		
H.P.						
F.T.						
Trionyx ferox	8	1	0	9		
H.P.	0.22	0.00	0.00	0.07	2.053	NS
F.T.	0.11	0.00	0.00	0.03	2.407	NS

(Continued)

(Sheet 4 of 5)

Table 2 (Concluded)

	Study Year 1977-78	1978-79	1979-80	Total	χ^2	
Trionyx ferox (egg clutches)	0	0	1	1		
H.P.						
F.T.						
SQUAMATA	(6)	(4)	(2)	(6)		
Coluber constrictor	2	0	0	2		
H.P.						
F.T.						
Farancia abacura	3	1	0	4		
H.P.						
F.T.	0.11	0.09	0.00	0.06	1.180	NS
Nerodia cyclopion	98	3	2	103		
H.P.	0.30	0.04	0.00	0.11	1.066	NS
F.T.	2.59	0.09_A	0.09_A	0.82	50.092	**
Nerodia fasciata	3	2	2	7		
H.P.						
F.T.	0.00	0.09	0.00	0.03	1.952	NS
Regina alleni	2	1	0	3		
H.P.						
F.T.	0.00	0.09	0.00	0.03	1.952	NS
Thamnophis sirtalis	2	0	0	2		
H.P.						
F.T.						

(Sheet 5 of 5)

Table 3

The distribution and relative density of amphibians and reptiles on the Middle Pool permanent shoreline site during the three-year study. Yearly site summaries include the number of species by major taxonomic unit (parentheses), the total number of individuals of a species seen or captured by all methods (raw values), and their mean relative density as estimated by two methods: herp-patrol (H.P. = mean number/hour) and funnel traps (F.T. = mean number/100 trap days). Chi-square values compare all three years (* = P<.05, ** = P<.01, NS = not significant). If significant between-year differences (P<.05) were detected, pair-wise comparisons of years were performed. Yearly means with the same letter indicate no significant difference between those years (P<.025). See text for details.

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Total herp-patrol	20.30	11.68	9.50	41.48	
Total trap days	424	457	480	1361	
AMPHIBIA	(8)	(7)	(6)	(8)	
CAUDATA	(2)	(2)	(1)	(2)	
Amphiuma means	14	3	0	17	
H.P.					
F.T.	2.83	0.66_A	0.00_A	1.10	17.798 **

(Continued)

(Sheet 1 of 5)

Table 3 (Continued)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
Siren lacertina	15	3	2	20		
H.P.						
F.T.	2.83	0.66_A	0.21_A	1.18	14.917	**
ANURA	(6)	(5)	(5)	(6)		
Acris gryllus (adults)	98	38	30	166		
H.P.	5.68	6.55	6.08	6.10	0.793	NS
F.T.						
Acris gryllus (larvae)	1	0	0	1		
H.P.						
F.T.	0.24	0.00	0.00	0.07	2.212	NS
Bufo terrestris (adults)	5	0	0	5		
H.P.	0.59	0.00	0.00	0.20	0.082	NS
F.T.						
Gastrophryne carolinensis (adults)	8	3	1	12		
H.P.	0.13	0.00	0.25	0.13	0.080	NS
F.T.						
Hyla cinerea (adults)	134	55	81	270		
H.P.	5.67	9.27	18.03	11.01	1.691	NS
F.T.						
Rana grylio (adults)	28	10	38	76		
H.P.	1.66	1.13	8.11	3.67	7.179	NS
F.T.	0.47	0.44	0.21	0.37	0.519	NS

(Continued)

(Sheet 2 of 5)

Table 3 (Continued)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
Rana grylio (larvae)	37	4	0	41		
H.P.						
F.T.	1.18	0.88	0.00	0.66	5.246	NS
Rana utricularia (adults)	14	28	81	123		
H.P.	1.10_{A}	2.95_{A}	16.00	6.74	10.293	*
F.T.	0.00	0.22	0.21	0.15	0.908	NS
Rana utricularia (larvae)	28	24	0	52		
H.P.						
F.T.	1.18	5.25	0.00	2.13	33.635	**
REPTILIA	(10)	(6)	(5)	(11)		
CROCODILIA	(1)	(1)	(1)	(1)		
Alligator mississippiensis	21	1	1	23		
H.P.	0.12	0.00	0.00	0.04	0.329	NS
F.T.						
TESTUDINATA	(6)	(2)	(2)	(6)		
Chrysemys floridana	31	0	5	36		
H.P.	1.02	0.00_{A}	0.35_{A}	0.46	10.417	*
F.T.	0.24	0.00	0.00	0.07	2.212	NS
Chrysemys nelsoni	8	2	0	10		
H.P.	0.25	0.07	0.00	0.11	2.437	NS
F.T.						

(Continued)

(Sheet 3 of 5)

Table 3 (Continued)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
Kinosternon bauri	1	0	0	1		
H.P.	0.03	0.00	0.00	0.01		NS
F.T.						
Kinosternon subrubrum	2	0	0	2		
H.P.						
F.T.	0.47	0.00	0.00	0.15	4.426	NS
Sternotherus odoratus	290	74	65	429		
H.P.	8.62	5.56	6.85	7.03	0.486	NS
F.T.	0.71	0.22	0.00	0.29	3.979	NS
Trionyx ferox	1	0	0	1		
H.P.	0.05	0.00	0.00	0.02	0.082	NS
F.T.						
Trionyx ferox (eggs)	0	3	0	3		
H.P.						
F.T.						
SQUAMATA	(3)	(3)	(2)	(4)		
Nerodia cyclopion	10	1	0	11		
H.P.						
F.T.	1.65	0.22_A	0.00_A	0.59	12.104	**
Nerodia fasciata	2	1	1	4		
H.P.						
F.T.	0.00	0.22	0.21	0.15	0.908	NS

(Continued)

(Sheet 4 of 5)

Table 3 (Concluded)

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Regina alleni	0	3	1	4	
H.P.					
F.T.	0.00	0.44	0.21	0.22	1.920 NS
Thamnophis sauritus	5	0	0	5	
H.P.					
F.T.					

(Sheet 5 of 5)

Table 4

The distribution and relative density of amphibians and reptiles on the East Pool permanent shoreline site during the three-year study. Yearly site summaries include the number of species by major taxonomic unit (parentheses), the total number of individuals of a species seen or captured by all methods (raw values), and their mean relative density as estimated by two methods: herp-patrol (H.P. = mean number/hour) and funnel traps (F.T. = mean number/100 trap days). Chi-square values compare all three years (* = P<.05, ** = P<.01, NS = not significant). If significant between-year differences (P<.05) were detected, pair-wise comparisons of years were performed. Yearly means with the same letter indicate no significant difference between those years (P<.025). See text for details.

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Total herp-patrol hours	10.36	9.03	10.00	29.39	
Total trap days	434	456	1120	2010	
AMPHIBIA	(7)	(6)	(7)	(8)	
CAUDATA	(3)	(2)	(3)	(4)	
Amphiuma means	143	38	24	205	
H.P.					
F.T.	30.41	8.33	1.43	9.25	313.558 **

(Continued)

(Sheet 1 of 4)

Table 4 (Continued)

	Study Year 1977-78	1978-79	1979-80	Total	χ^2	
<u>Eurycea</u> <u>quadridigitata</u>	2	0	0	2		
H.P.						
F.T.						
<u>Pseudobranchus</u> <u>striatus</u>	0	0	1	1		
H.P.						
F.T.						
<u>Siren</u> <u>lacertina</u>	37	15	22	74		
H.P.	0.14	0.25	1.73	0.72	7.472	NS
F.T.	6.91	2.19	0.18	2.09	69.358	**
ANURA	(4)	(4)	(4)	(4)		
<u>Acris</u> <u>gryllus</u> (adults)	78	68	103	249		
H.P.	8.00	11.88	21.44	13.88	2.403	NS
F.T.						
<u>Hyla</u> <u>cinerea</u> (adults)	383	108	164	655		
H.P.	46.81	16.88	39.69	34.53	0.946	NS
F.T.						
<u>Hyla</u> <u>cinerea</u> (larvae)	14	0	1	15		
H.P.						
F.T.	2.07	0.00_A	0.00_A	0.45	32.829	**
<u>Rana</u> <u>grylio</u> (adults)	16	16	24	56		
H.P.	1.37	2.07	3.64	2.38	1.304	NS
F.T.	0.92_A	0.44_{AB}	0.09_B	0.35	6.383	*

(Continued)

(Sheet 2 of 4)

Table 4 (Continued)

	Study Years 1977–78	1978–79	1979–80	Total	χ^2	
Rana grylio (larvae)	6	1	3	10		
H.P.						
F.T.	1.38_A	0.22_{AB}	0.18_B	0.45	10.861	**
Rana utricularia (adults)	27	14	6	47		
H.P.	5.51	2.47	0.85	2.91	0.437	NS
F.T.	0.00	0.22	0.00	0.05	3.410	NS
Rana utricularia (larvae)	5	12	0	17		
H.P.						
F.T.	0.92_A	2.63_A	0.00	0.80	28.529	**
REPTILIA	(8)	(7)	(7)	(7)		
CROCODILIA	(1)	(1)	(1)	(1)		
Alligator mississippiensis	1	3	1	5		
H.P.						
F.T.						
TESTUDINATA	(5)	(5)	(5)	(5)		
Chelydra serpentina	1	2	2	5		
H.P.						
F.T.	0.23	0.44	0.18	0.25	0.891	NS
Chrysemys floridana	15	9	43	67		
H.P.	0.95	0.77	1.64	1.13	1.796	NS
F.T.	0.23	0.00	0.00	0.05	3.633	NS

(Continued)

Table 4 (Concluded)

	Study Years					
	1977-78	1978-79	1979-80	Total	χ^2	
Chrysemys nelsoni	3	1	6	10		
H.P.	0.17	0.10	0.11	0.13	0.216	NS
F.T.						
Sternotherus odoratus	44	9	13	66		
H.P.	6.02	0.65	0.51	2.37	4.749	NS
F.T.	0.00	0.22	0.09	0.10	1.102	NS
Sternotherus odoratus (eggs)	2	0	0	2		
H.P.						
F.T.						
Trionyx ferox	2	1	1	4		
H.P.	0.15	0.00	0.00	0.05	0.348	NS
F.T.						
SQUAMATA	(2)	(1)	(1)	(2)		
Nerodia cyclopion	20	7	17	44		
H.P.	0.10	0.11	0.00	0.07	0.089	NS
F.T.	3.46	0.66_A	0.62_A	1.24	22.061	**
Thamnophis sauritus	1	0	0	1		
H.P.						
F.T.						

(Sheet 4 of 4)

Table 5

The distribution and relative density of amphibians and reptiles on the West Pool permanent shoreline site during the three-year study. Yearly site summaries include the number of species by major taxonomic unit (parentheses), the total number of individuals of a species seen or captured by all methods (raw values), and their mean relative density as estimated by two methods: herp-patrol (H.P. = mean number/hour) and funnel traps (F.T. = mean number/100 trap days). Chi-square values compare all three years (* = P<.05, ** = P<.01, NS = not significant). If significant between-year differences (P<.05) were detected, pair-wise comparisons of years were performed. Yearly means with the same letter indicate no significant difference between those years (P<.025). See text for details.

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Total herp-patrol hours	14.40	12.16	10.23	36.79	
Total trap days	614	837	782	2233	
AMPHIBIA	(7)	(7)	(5)	(8)	
CAUDATA	(2)	(2)	(1)	(2)	
Amphiuma means	62	23	3	88	
H.P.					
F.T.	9.45	2.63	0.38	3.72	83.366 **

(Continued)

(Sheet 1 of 4)

Table 5 (Continued)

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Siren lacertina	23	7	0	30	
H.P.	0.09	0.00	0.00	0.03	0.329 NS
F.T.	1.63_A	0.84_A	0.00	0.76	12.175 **
ANURA	(5)	(5)	(4)	(6)	
Acris gryllus (adults)	11	2	0	13	
H.P.	0.00	0.24	0.00	0.08	0.088 NS
F.T.					
Bufo terrestris (adults)	0	0	12	12	
H.P.	0.00	0.00	2.30	0.78	0.082 NS
F.T.					
Gastrophryne carolinensis (adults)	57	40	42	139	
H.P.	2.81	5.28	7.56	5.22	0.793 NS
F.T.	0.00	0.12	0.00	0.04	1.669 NS
Hyla cinerea (adults)	538	370	139	1047	
H.P.	29.82	52.29	26.05	35.82	0.276 NS
F.T.	0.00	0.12	0.00	0.04	1.669 NS
Hyla cinerea (larvae)	2	0	0	2	
H.P.					
F.T.	0.16	0.00	0.00	0.04	2.638 NS
Rana grylio (adults)	0	17	0	17	
H.P.	0.00	2.16	0.00	0.70	2.187 NS
F.T.					

(Continued)

(Sheet 2 of 4)

Table 5 (Continued)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
Rana utricularia (adults)	50	34	21	105		
H.P.	1.78	3.73	2.83	2.76	1.020	NS
F.T.	0.16	0.00	0.00	0.04	2.638	NS
Rana utricularia (larvae)	2	2	0	4		
H.P.						
F.T.	0.00	0.24	0.00	0.09	3.339	NS
Rana utricularia (eggs)	4	0	0	4		
H.P.						
F.T.						
REPTILIA	(6)	(6)	(4)	(7)		
CROCODILIA	(0)	(0)	(0)	(0)		
TESTUDINATA	(5)	(4)	(4)	(5)		
Chelydra serpentina	1	4	2	7		
H.P.	0.00	0.16	0.00	0.05	0.088	NS
F.T.	0.00	0.12	0.13	0.09	0.762	NS
Chrysemys floridana	3	3	2	8		
H.P.	0.11	0.10	0.06	0.09	0.073	NS
F.T.						
Chrysemys nelsoni	2	2	1	5		
H.P.	0.05	0.00	0.06	0.04	0.080	NS
F.T.						

(Continued)

(Sheet 3 of 4)

Table 5 (Concluded)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
Kinosternon subrubrum	1	0	0	1		
H.P.						
F.T.						
Sternotherus odoratus	53	45	21	119		
H.P.	2.44	2.49	1.44	2.12	0.657	NS
F.T.	0.49	0.24	0.00	0.22	3.689	NS
SQUAMATA	(1)	(2)	(0)	(2)		
Nerodia cyclopion	13	4	0	17		
H.P.	0.32	0.08	0.00	0.14	0.582	NS
F.T.	0.16	0.12	0.00	0.09	1.153	NS
Nerodia fasciata	0	3	0	3		
H.P.						
F.T.	0.00	0.24	0.00	0.09	3.339	NS

(Sheet 4 of 4)

Table 6

The distribution and relative density of amphibians and reptiles on the Gatlin Canal permanent shoreline site during the three-year study. Yearly site summaries include the number of species by major taxonomic unit (parentheses), the total number of individuals of a species seen or captured by all methods (raw values), and their mean relative density as estimated by two methods: herp-patrol (H.P. = mean number/hour) and funnel traps (F.T. = mean number/100 trap days). Chi-square values compare all three years (* = P<.05, ** = P<.01, NS = not significant). If significant between-year differences (P<.05) were detected, pair-wise comparisons of years were performed. Yearly means with the same letter indicate no significant difference between those years (P<.025). See text for details.

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Total herp-patrol hours	26.35	19.40	16.00	61.75	
Total trap days	420	457	440	1317	
AMPHIBIA	(8)	(8)	(8)	(8)	
CAUDATA	(2)	(2)	(2)	(2)	
Amphiuma means	7	7	2	16	
H.P.	0.00	0.05	0.00	0.02	
F.T.	1.67	1.31	0.45	1.14	2.992 NS

(Continued)

(Sheet 1 of 5)

Table 6 (Continued)

	Study Year 1977-78	1978-79	1979-80	Total	χ^2	
Siren lacertina	6	3	4	13		
H.P.	0.11	0.00	0.09	0.07	0.579	NS
F.T.	0.71	0.66	0.23	0.53	1.171	NS
ANURA	(6)	(6)	(6)	(6)		
Acris gryllus (adults)	14	12	14	40		
H.P.	0.57	0.65	1.56	0.94	0.066	NS
F.T.						
Bufo terrestris (adults)	25	17	33	75		
H.P.	0.57	0.87	2.49	1.33	0.554	NS
F.T.						
Bufo terrestris (larvae)	1	2	0	3		
H.P.	0.00	0.11	0.00	0.04		
F.T.						
Hyla cinerea (adults)	59	137	210	406		
H.P.	2.45	7.31	12.18	7.39	1.314	NS
F.T.						
Gastrophryne carolinensis (adults)	4	4	1	9		
H.P.	0.13	0.22	0.07	0.14	0.096	NS
F.T.						
Rana grylio (adults)	2	20	50	72		
H.P.	0.06_A	0.86_A	2.88	1.29	13.143	*
F.T.	0.00^A	0.66	0.68	0.46	2.825	NS

(Continued)

Table 6 (Continued)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
Rana grylio (larvae)	0	3	4	7		
H.P.						
F.T.	0.00	0.66	0.91	0.53	3.566	NS
Rana utricularia (adults)	30	55	38	123		
H.P.	1.01	2.93	2.42	2.12	4.468	NS
F.T.	0.00	0.44	0.00	0.15	3.769	NS
Rana utricularia (larvae)	0	2	1	3		
H.P.						
F.T.	0.00	0.44	0.23	0.23	1.844	NS
REPTILIA	(10)	(11)	(8)	(12)		
CROCODILIA	(0)	(1)	(1)	(1)		
Alligator mississippiensis	0	2	2	4		
H.P.	0.00	0.12	0.08	0.07	0.252	NS
F.T.						
TESTUDINATA	(8)	(7)	(5)	(8)		
Chelydra serpentina	2	5	0	7		
H.P.	0.09	0.00	0.00	0.03	0.348	NS
F.T.	0.00_A	1.09	0.00_A	0.38	9.445	**
Chrysemys floridana	52	29	22	103		
H.P.	0.83	1.49	0.97	1.10	1.303	NS
F.T.						

(Continued)

(Sheet 3 of 5)

Table 6 (Continued)

	Study Year 1977-78	1978-79	1979-80	Total	χ^2	
<u>Chrysemys</u> <u>nelsoni</u>	27	27	9	63		
H.P.	0.63	1.30	0.55	0.82	5.498	NS
F.T.						
<u>Deirochelys</u> <u>reticularia</u>	1	2	0	3		
H.P.	0.04	0.14	0.00	0.06		
F.T.						
<u>Kinosternon</u> <u>bauri</u>	1	1	1	3		
H.P.						
F.T.	0.24	0.00	0.23	0.15	1.066	NS
<u>Kinosternon</u> <u>subrubrum</u>	7	2	0	9		
H.P.	0.06	0.03	0.00	0.03	0.264	NS
F.T.	0.24	0.22	0.00	0.15	1.010	NS
<u>Sternotherus</u> <u>odoratus</u>	306	49	17	372		
H.P.	6.61	1.89_A	0.69_A	3.03	23.261	**
F.T.	2.38	1.75	0.68	1.59	4.062	NS
<u>Sternotherus</u> <u>odoratus</u> (eggs)	1	0	0	1		
H.P.						
F.T.						
<u>Trionyx</u> <u>ferox</u>	6	0	1	7		
H.P.	0.07	0.00	0.05	0.04	0.252	NS
F.T.						

(Continued)

(Sheet 4 of 5)

Table 6 (Concluded)

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
SQUAMATA	(2)	(3)	(2)	(3)	
Farancia abacura	0	1	0	1	
H.P.					
F.T.					
Nerodia cyclopion	19	4	1	24	
H.P.	0.40	0.09	0.00	0.16	2.544 NS
F.T.	0.95	0.44	0.23	0.53	2.254 NS
Nerodia fasciata	14	5	3	22	
H.P.	0.38	0.16	0.06	0.20	3.416 NS
F.T.	0.24	0.00	0.23	0.15	1.066 NS

(Sheet 5 of 5)

Table 7

The distribution and relative density of amphibians and reptiles for all permanent shoreline sites combined during the three-year study. Yearly site summaries include the number of species by major taxonomic unit (parentheses), the total number of individuals of a species seen or captured by all methods (raw values), and their mean relative density as estimated by two methods: herp-patrol (H.P. = mean number/hour) and funnel traps (F.T. = mean number/100 trap days). Chi-square values compare all three years (* = P<.05, ** = P<.01, NS = not significant). If significant between-year differences (P<.05) were detected, pair-wise comparisons of years were performed. Yearly means with the same letter indicate no significant difference between those years (P<.025). See text for details.

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Total herp-patrol hours	103.36	69.62	60.16	233.14	
Total trap days	2820	3278	3984	10082	
AMPHIBIA	(10)	(9)	(9)	(11)	
CAUDATA	(3)	(2)	(3)	(4)	
Amphiuma means	247	74	29	350	
H.P.	0.00	0.01	0.00	0.00	
F.T.	8.16	2.14	0.53	3.18	329.84 **

(Continued)

(Sheet 1 of 7)

Table 7 (Continued)

	Study Year 1977-78	1978-79	1979-80	Total	X^2	
Amphiuma means (eggs)	0	2	0	2		
H.P.						
F.T.						
Eurycea quadridigitata	2	0	0	2		
H.P.						
F.T.						
Pseudobranchus striatus	0	0	1	1		
H.P.						
F.T.						
Siren lacertina	82	34	31	147		
H.P.	0.07	0.08	0.36	0.17	1.135	NS
F.T.	1.95	0.79	0.10	0.84	67.742	**
	(7)	(7)	(6)	(7)		
ANURA						
Acris gryllus (adults)	704	253	279	1236		
H.P.	6.11	7.04	9.43	7.54	0.422	NS
F.T.						
Acris gryllus (larvae)	1	0	0	1		
H.P.	0.04	0.00	0.00	0.01	2.575	NS
F.T.						
Bufo terrestris (adults)	38	18	47	103		
H.P.	0.29	0.19	1.01	0.50	0.207	NS
F.T.						

(Continued)

(Sheet 2 of 7)

Table 7 (Continued)

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
<u>Bufo terrestris</u> (larvae)	1	2	0	3	
H.P.	0.00	0.02	0.00	0.01	
F.T.					
<u>Gastrophryne carolinensis</u> (adults)	74	50	45	169	
H.P.	0.62	1.17	1.60	1.14	0.475 NS
F.T.	0.00	0.03	0.00	0.01	2.076 NS
<u>Hyla cinerea</u> (adults)	1151	704	605	2460	
H.P.	17.04	17.90	19.41	18.13	0.437 NS
F.T.	0.00	0.03	0.00	0.01	2.076 NS
<u>Hyla cinerea</u> (larvae)	17	0	1	18	
H.P.					
F.T.	0.39	0.00_A	0.00_A	0.11	28.358 **
<u>Hyla squirella</u> (adults)	7	10	0	17	
H.P.	0.02	0.11	0.00	0.04	
F.T.					
<u>Rana grylio</u> (adults)	47	63	113	223	
H.P.	0.62	1.24	2.93	1.61	6.606 NS
F.T.	0.21	0.21	0.13	0.18	1.040 NS
<u>Rana grylio</u> (larvae)	43	8	7	58	
H.P.					
F.T.	0.39	0.24	0.15	0.25	3.831 NS

(Continued)

Table 7 (Continued)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
<u>Rana utricularia</u> (adults)	151	175	162	488		
H.P.	2.12	2.87	4.86	3.30	3.825	NS
F.T.	0.04	0.12	0.03	0.06	3.221	NS
<u>Rana utricularia</u> (larvae)	36	44	1	81		
H.P.						
F.T.	0.35	1.34	0.03	0.55	60.137	**
<u>Rana utricularia</u> (eggs)	5	0	0	5		
H.P.						
F.T.						
REPTILIA	(16)	(14)	(11)	(17)		
CROCODILIA	(1)	(1)	(1)	(1)		
<u>Alligator mississippiensis</u>	22	6	4	32		
H.P.	0.03	0.02	0.02	0.02	0.018	NS
F.T.						
TESTUDINATA	(8)	(9)	(7)	(9)		
<u>Chelydra serpentina</u>	4	12	4	20		
H.P.	0.02	0.03	0.00	0.02	0.051	NS
F.T.	0.04_A	0.24	0.08_A	0.12	6.607	*
<u>Chrysemys floridana</u>	194	51	76	321		
H.P.	0.87	0.55	0.63	0.68	8.908	NS
F.T.	0.07	0.00	0.00	0.02	5.151	NS

(Continued)

(Sheet 4 of 7)

Table 7 (Continued)

	Study Year 1977-78	1978-79	1979-80	Total	χ^2	
Chrysemys nelsoni	52	34	20	106		
H.P.	0.24	0.31	0.18	0.24	1.846	NS
F.T.	0.04	0.00	0.00	0.01	2.575	NS
Chrysemys scripta	0	2	0	2		
H.P.						
F.T.	0.00	0.03	0.00	0.01	2.076	NS
Deirochelys reticularia	1	2	0	3		
H.P.	0.01	0.03	0.00	0.01		
F.T.						
Kinosternon bauri	8	2	3	13		
H.P.	0.01	0.00	0.00	0.00		
F.T.	0.07	0.00	0.03	0.03	2.611	NS
Kinosternon subrubrum	48	6	3	57		
H.P.	0.04	0.03	0.02	0.03	0.199	NS
F.T.	0.96	0.06_A	0.00_A	0.29	61.474	**
Sternotherus odoratus	1032	292	229	1553		
H.P.	5.74	3.21_A	3.16_A	4.04	13.548	**
F.T.	0.96	0.46	0.10	0.46	26.705	**
Sternotherus odoratus (eggs)	3	2	0	5		
H.P.						
F.T.						

(Continued)

(Sheet 5 of 7)

Table 7 (Continued)

	Study Year					
	1977-78	1978-79	1979-80	Total	χ^2	
Trionyx ferox	17	2	2	21		
H.P.	0.10	0.00	0.01	0.04	1.532	NS
F.T.	0.04	0.00	0.00	0.01	2.575	NS
Trionyx ferox (eggs)	0	3	4	7		
H.P.						
F.T.						
SQUAMATA	(7)	(4)	(3)	(7)		
Coluber constrictor	2	0	0	2		
H.P.						
F.T.						
Farancia abacura	3	2	0	5		
H.P.						
F.T.	0.04	0.03	0.00	0.02	1.326	NS
Nerodia cyclopion	160	19	20	199		
H.P.	0.22	0.06	0.00	0.10	2.584	NS
F.T.	1.81	0.24_A	0.23_A	0.67	75.167	**
Nerodia fasciata	19	11	7	37		
H.P.	0.07	0.03	0.01	0.04	0.713	NS
F.T.	0.04	0.12	0.05	0.07	1.988	NS
Regina alleni	2	4	1	7		
H.P.						
F.T.	0.00	0.09	0.03	0.04	3.554	NS

(Continued)

(Sheet 6 of 7)

Table 7 (Concluded)

	Study Year				
	1977-78	1978-79	1979-80	Total	χ^2
Thamnophis sauritus	6	0	0	6	
H.P.					
F.T.					
Thamnophis sirtalis	2	0	0	2	
H.P.					
F.T.					

(Sheet 7 of 7)

LARGE-SCALE OPERATIONS MANAGEMENT TEST

Methods for Estimating the Depth of a Radiotagged Fish

by

Malcolm P. Keown*

As part of the Aquatic Plant Control Research Program, WES is conducting research to develop biological methods for the control of problem aquatic plants. A Large-Scale Operations Management Test was initiated in 1976 at Lake Conway, Florida (Figure 1), to evaluate the use of the white amur fish (*Ctenopharyngodon idella*) as an operational method for the control of excessive hydrilla growth (*Hydrilla verticillata*).** Since the stocking of Lake Conway with white amur in September 1977, aquatic plant sampling operations by the Florida Department of Natural Resources (DNR) have indicated a definite reduction of hydrilla populations due to the presence of the fish. What could not be determined from these observations was a correlation between fish movement within the lake system and the decline or occurrence of the macrophytes as a function of time. The examination of this problem indicated that radiotracking fish movements at comparable time intervals to the other data-collection efforts would provide the needed information.

A mobile unit with a dual Yagi antenna array (Figure 2) was assembled by WES at Lake Conway in May 1979 for tracking radiotagged fish. Since then more than 20 white amur have been tagged and tracked by DNR personnel. Two methods have been used to locate the surface position of the tagged fish: simple triangulation and the pursuit method. The triangulation method of acquiring data proved to be somewhat inefficient. A quicker and probably more accurate method was developed as a result of field experience. Using the second approach, termed the pursuit method, the antenna array is oriented broadside with the direction of travel of the mobile tracking unit. The operator of the craft, using an onboard radio receiver connected to the antenna, proceeds in the direction of maximum signal strength. As the tracking unit passes over the location of a tagged fish, there is a drastic reduction in signal strength; this reduction is explained by the fact that the front-to-back ratio of the antenna array is in excess of 20 db. After passing over the fish, the tracking unit then circles back to the

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

** Keown, M. P. 1980 (Jul). "Radiotelemetry Tracking at Lake Conway," Aquatic Plant Control Research Program Information Exchange Bulletin, Vol A-80-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

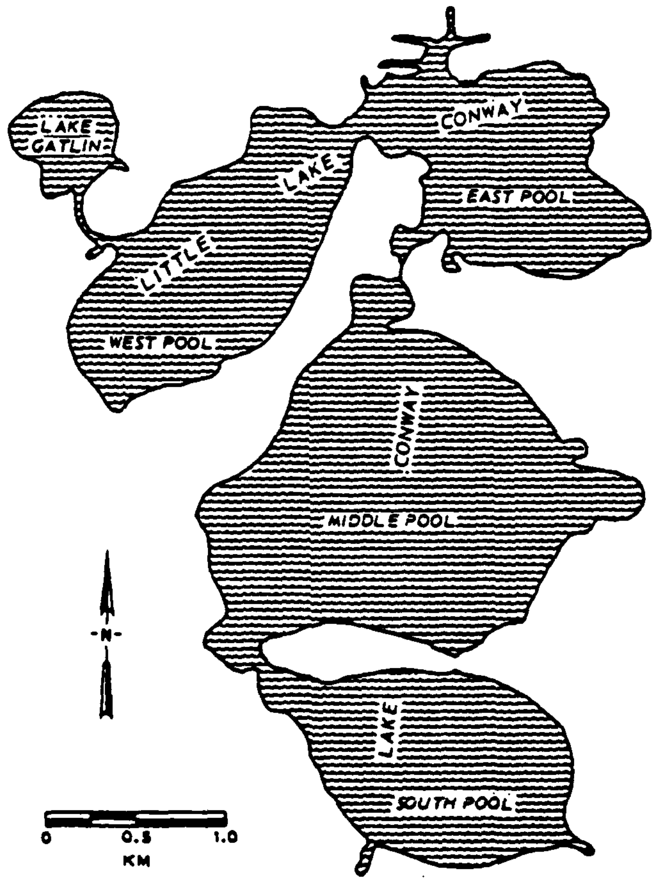

Figure 1. Chain of lakes that comprise the Lake Conway system

Figure 2. Mobile tracking unit at Lake Conway, Florida

estimated position of the fish to verify the location. If the craft is maneuvered rapidly, the wake forms an "x" at the estimated location of the fish. Use of the mobile tracking unit in conjunction with the pursuit method has proven to be a reliable technique to determine the surface location of a tagged fish. Comparisons of estimated locations with known locations have indicated that the difference is generally less than 5 m.

The procedures developed to locate tagged fish with the mobile tracking unit can only be used to determine the surface location of a tagged individual. As part of the radiotracking study at Lake Conway, an attempt is being made by WES to develop a technique to estimate tag depth, which would give an x-, y-, and z-coordinate location. The initial method used to estimate depth accounted for all signal losses (and gains) along the propagation path between the underwater radio tag and an above-water antenna and receiver. The second method also accounted for signal losses (and gains) along the propagation path, but differed from the first approach in that the receiving antenna was positioned below the water surface.

Estimation of Radiotag Depth Using An Above-Water Receiving Antenna

As a radio signal travels away from a tag towards an above-water receiving antenna, attenuation is experienced over three distinct parts of the propagation path: through the water, at the air/water interface,

and through the air (Figure 3). The unit attenuation A_1 through water (db/m) can be estimated from:

$$A_1 = 0.1635 \left(\frac{\sigma}{\sqrt{\varepsilon_r}}\right) \tag{1}$$

where

σ = electrical conductivity of water at the signal frequency, micromhos/cm

ε_r = dielectric constant of water (varies from 87 at 1.5°C to 78 at 25°C for frequencies from 10 to 100 MHz)

As the radio signal approaches the air/water interface, only the portion of the incident signal that makes an included angle of 6.4 deg or less with the water surface normal is propagated across the interface (Figure 3). The remainder of the signal is reflected into the water; thus, less than 0.5 percent of the power radiated from the tag is available to be transmitted across the interface, exclusive of the losses incurred due to water attenuation between the tag and the surface. Once the signal has crossed the interface, the remaining energy is distributed into vertically and horizontally polarized components spread through the radiation hemisphere.

The signal loss at the air/water interface is a function of the dielectric constant of the water and the viewing angle in air (Figure 3),

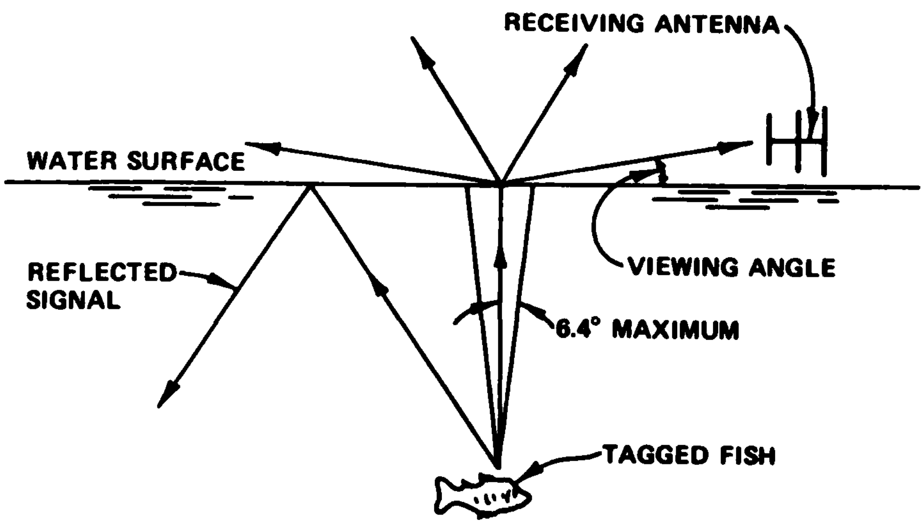

Figure 3. Signal propagation path between an underwater radio-tagged fish and an above-water receiving antenna

i.e., the included angle between the water surface and the path between the source of radiation (the location on the interface where the signal is being radiated from) and the receiving antenna. Measurements by other investigators have shown that this loss is 27 to 30 db for viewing angles of 10 to 5 deg.*

Once the signal has crossed the air/water interface, it suffers further attenuation through air until the receiving antenna is reached. This signal attenuation A_2 (db) can be computed from:

$$A_2 = 22 + 10 \log_{10} \left(\frac{d}{\lambda}\right)^2 \tag{2}$$

where

d = length of propagation path in air over which attenuation is being measured, m

λ = wavelength of radio signal in air, m

Thus, if the effective radiated power of a fish tag is known, in addition to the gain of the receiving antenna, the loss in the transmission line between the antenna and receiver, and the signal noise floor of the receiver, then the only unknown along the signal propagation path is the attenuation between the tag and water surface. This attenuation A_w (db) can be computed as follows:

$$A_w = P_L - S_L - A_2 + Y_G - T_L \tag{3}$$

where

P_L = propagation path loss (db) which is equal to the absolute value of the difference between the receiver noise floor (dbm) and the effective radiated power of the fish tag, dbm

S_L = signal loss across air/water interface, db

A_2 = signal loss through air, db (Equation 2)

Y_G = gain of receiving antenna over a reference point source, db

T_L = signal loss through the transmission line connecting the antenna and receiver, db

The unit attenuation of a radio signal (computed from Equation 1 or measured in the field) travelling through water is constant for a given electrical conductivity and temperature. Thus, knowing this constant, the depth D (m) of a tagged fish is:

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* Velle, J. I. et al. 1979. "An Investigation of the Loss Mechanisms Encountered in Propagation from a Submerged Fish Telemetry Transmitter," Proceedings, Second International Conference on Wildlife Biotelemetry, pp 228-237, Laramie, Wyoming.

$$D = \frac{A_w \text{ (db)}}{A_1 \text{ (db/m)}} \tag{4}$$

As an example, consider a fish at an unknown depth in Lake Conway whose tag radiates a signal at 49 MHz with a strength of -70 dbm. The mobile tracking unit is 40 m away from the estimated surface position of the tagged fish (a viewing angle of 5 deg; at this angle, the loss across the air/water interface is estimated to be 30 db according to Velle et al. (1979)); the gain of the dual Yagi antenna system on the mobile tracking unit is 13 db with a 1-db loss in the transmission line between the antenna and receiver (noise floor is -135 dbm). The signal loss through air can be computed from Equation 2, as follows:

$$A_2 = 22 + 10 \log_{10} \left(\frac{40}{6}\right)^2 = 38 \text{ db}$$

Then, from Equation 3:

$$A_w = |-135-(-70)| - 30 - 38 + 13 - 1 = 9 \text{ db}$$

The measured conductivity of the Lake Conway water is 4 db/m. The estimated depth of the tagged fish can now be calculated from Equation 4:

$$D = \frac{9 \text{ db}}{4 \text{ db/m}} = 2.25 \text{ m}$$

Extensive tests to verify this method were conducted at Lake Conway and WES; however, severe signal fading cast considerable doubt over the validity of the depth estimates. Examination of the test data and the theory underlying the propagation of a radio signal over the complex media path indicated that the fading was probably a result of one or more of the following:

a. Scattering of the signal across the air/water interface. Note that the wavelength of a 49-MHz radio signal underwater is only 0.68 m, and thus could be comparable to the length of a surface wave slope.

b. The estimate of signal attenuation across the air/water interface.

c. Reflection of the tag signal from the lake bottom and subsequent propagation across the air/water interface at a location on the surface other than above the tagged fish.

Estimate of Radiotag Depth Using an Underwater Antenna

Consideration of the problems noted above when estimating the depth of a radiotagged fish with an above-water receiving antenna indicated that problems a and b could be eliminated by using a directional underwater antenna. Using this approach, the signal would not have to cross the air/water interface which would, hopefully, eliminate the fading problem. With this method the underwater antenna would have to be constructed such that when the array was rotated through the horizontal plane, the radiation pattern would respond correctly to the azimuth between the antenna and the radiotagged fish. Then, assuming the antenna was oriented correctly in the horizontal plane in the direction of the radiotagged fish, and the distance from the antenna to the fish could be determined, then the depth (m) of the fish could be estimated as follows (Figure 4):

$$D = D_1 + R \sin \theta \qquad (5)$$

where

D_1 = depth of the antenna below the water surface, m

R = distance from the antenna to the tagged fish, m

θ = included vertical angle between the horizontal and a line laid out along the axis of the antenna boom to the tagged fish

Experiments were conducted at WES from February through September 1980 to evaluate the feasibility of this approach. Several directional antenna arrays were considered. A two element driven dipole array was selected because of its relative insensitivity to element length, ease of electrical impedance matching, and simple mechanical construction (Figure 5). The antenna was fed with a Wilkinson power divider to minimize mutual coupling between the dipoles and to provide a 50 Ω impedance match to each dipole (Figure 5).

The antenna was constructed such that the dipoles could be spaced either one-quarter wavelength ($\lambda/4$) apart or three-quarters wavelength ($3\lambda/4$) apart. With the dipoles spaced $\lambda/4$ apart and with a $\lambda/4$ phase delay line in the feed line of the lead dipole (Figure 5), the signals fed to the receiver through the power divider are in phase (or additive), resulting in an antenna radiation pattern that exhibits a peak in the direction of a signal source; i.e., as the antenna is rotated, maximum signal strength is realized at the receiver input when the incoming signal is perpendicular to the dipoles (Figure 5). When the dipoles are spaced $3\lambda/4$ apart, the signals fed to the receiver are 180 deg out of phase, and a null results in the antenna radiation pattern; i.e., when the elements are perpendicular to the incoming signal, the signal strength at the receiver input is at a minimum.

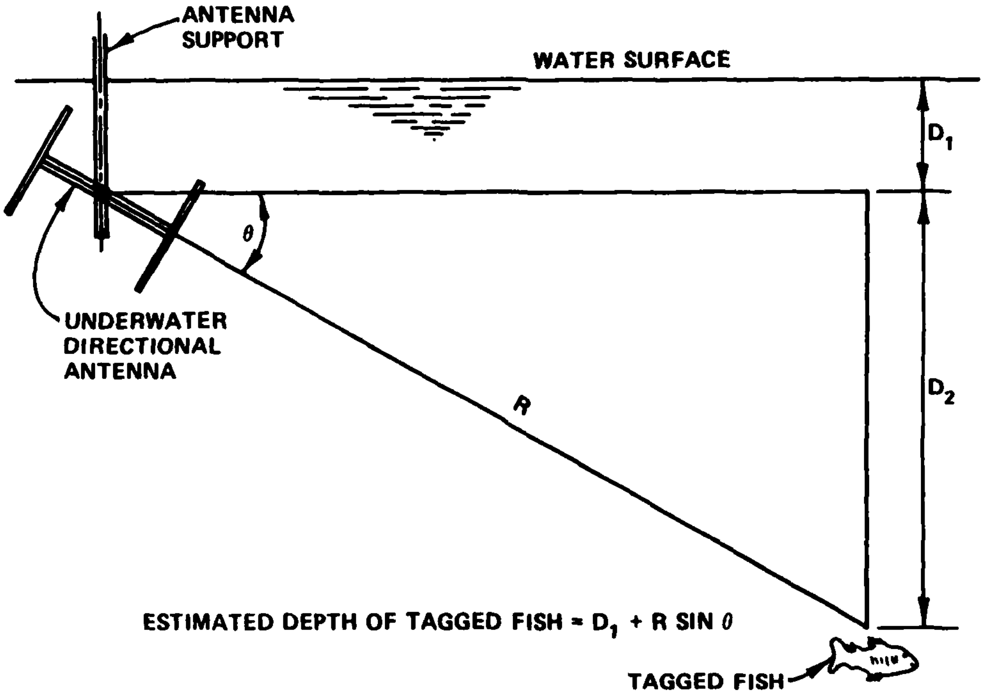

Figure 4. Estimation of radiotagged fish depth using an underwater antenna

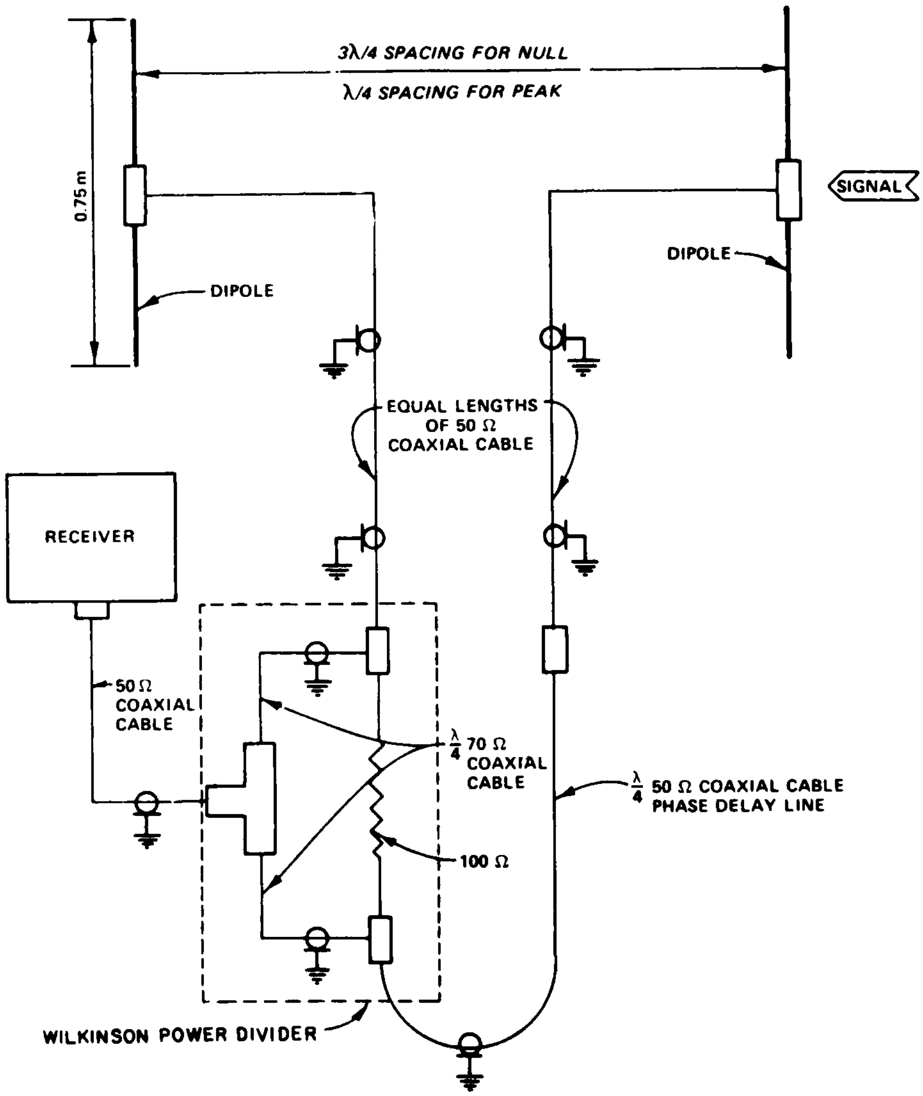

Figure 5. Schematic diagram of two element driven dipole array fed by a Wilkinson power divider

Tests to evaluate the feasibility of estimating the depth of a radiotagged fish with the two element driven dipole array were conducted in a sump (11 m × 28.5 m) made available by the WES Hydraulics Laboratory. During the evaluation period, the water temperature in the sump was 25°C and the depth was 2.5 m.

The dipole array was initially tested to determine its angular resolution in the horizontal plane, i.e. how accurately could the angle between a reference azimuth and a line laid out from the antenna to a fish tag be measured. (Note that the tags used throughout these tests described herein were not implanted in fish.) With the dipoles spaced $3\lambda/4$ apart (null in the antenna radiation pattern), the test results indicated that there was no significant error in estimating the azimuthal angle.

The second step in the test sequence was to develop a procedure to estimate the distance between the dipole array and a fish tag, i.e., to obtain R in Equation 5. The dipoles were spaced $\lambda/4$ apart to obtain a peak in the radiation pattern; the signal strength (db) of a tag at various distances between the antenna and the tag was then measured as referenced to the receiver noise floor.* Four tags were used to make 250 measurements at distances between the antenna and tag of 2 to 13 m. The results were plotted on semilogarithmic paper and an error band was manually laid out around the cluster of data points. The upper and lower solid lines in Figure 6 which form the error band represent the maximum and minimum spread of signal strengths measured at given distances between the antenna and the tag. A dashed line was laid out on the plot midway between the upper and lower lines to represent a best estimate of the distance between the antenna and a fish tag as determined by the tag signal strength above the receiver noise floor. Thus, if a signal is 50 db above the receiver noise floor, the distance between the antenna and tag can be estimated as 3 m (from dashed line in Figure 6); however, this value could vary $\pm$ 1 m as determined by the solid lines forming the error band. With a signal strength of 20 db above the noise floor, the distance estimate is 10 m; however, the potential error has increased to $\pm$ 2 m. Note that the distance between the antenna and fish tag in Figure 6 is limited to a range of 2 to 13 m. At distances of 2 m or less, the receiver experienced front-end overloading; beyond 13 m signals were marginal in many cases, and measurements of tag signal strengths above the receiver noise floor often became difficult due to slight fading.

The dipole array was adjusted to $3\lambda/4$ spacing between the elements (null in radiation pattern) to estimate the vertical angle, i.e., to obtain θ in Equation 5. During this part of the test sequence, the antenna was supported by a structure made of polyvinyl chloride (PVC) pipe, whose nonconductive properties would not detune the antenna

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* The gain of the antenna array was estimated to be 6 db above an isotropic source; the loss in the transmission line between the antenna array and receiver was 3 db; thus, 3 db was subtracted from the measurement of each signal strength above the receiver noise floor.

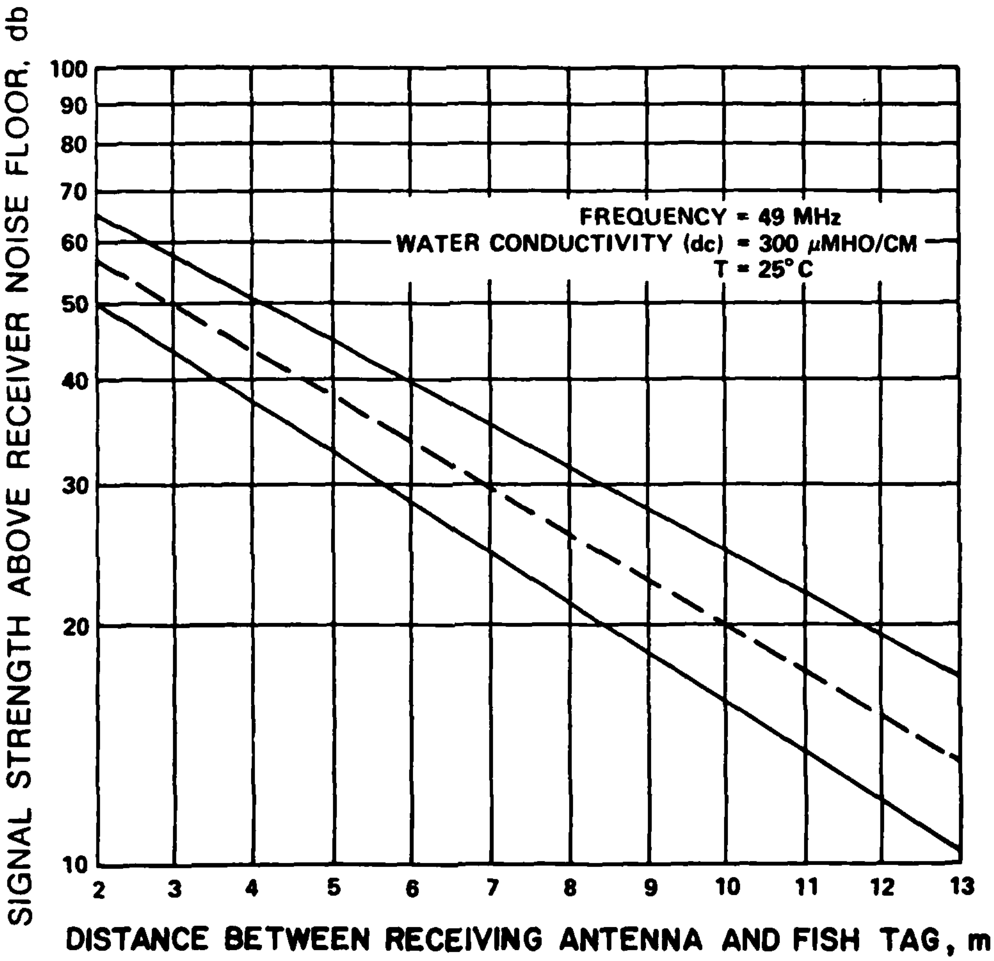

Figure 6. Graph to estimate distance between receiving antenna and fish tag as determined by measuring the tag's signal strength above the receiver noise floor. Solid lines represent the maximum and minimum spread of signal strengths measured at given distances between the antenna and the fish tag. The dashed line was plotted midway between the upper and lower solid lines to represent a best estimate of the distance for a given signal strength above the receiver noise floor (T = temperature)

(Figures 7 and 8). After placing the PVC pipe support structure and antenna in the sump (Figure 9), the antenna was manually rotated from shore by a cable and counterweight assembly attached to the opposite end of the antenna boom (Figure 10). This assembly had a maximum error of 1 deg at angles $\pm$ 15 deg of the horizontal. Extensive testing with the antenna positioned near the water surface, at middepth, and near the bottom of the sump showed that errors in the vertical angle estimate up to 10 deg could be typically expected at distances of 8 to 13 m between the antenna and tag. At distances less than 8 m, the signals reflected from the air/water interface and from the concrete bottom of the sump distorted the radiation pattern of the antenna array; i.e., the null was no longer clearly detectable as the array was rotated through the vertical plane.

Thus, error in determining tag depth can result from a poor estimate of the distance between the . tenna and the tag and/or an error in

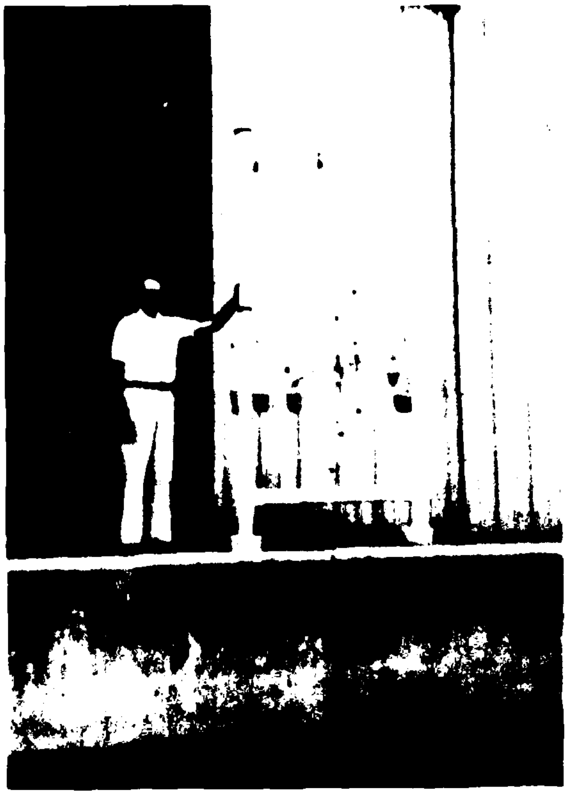

Figure 7. Polyvinyl chloride pipe structure used to support antenna array during tests to estimate the vertical angle θ (Equation 5)

Figure 8. Two element driven dipole array on rotating member of PVC pipe support structure

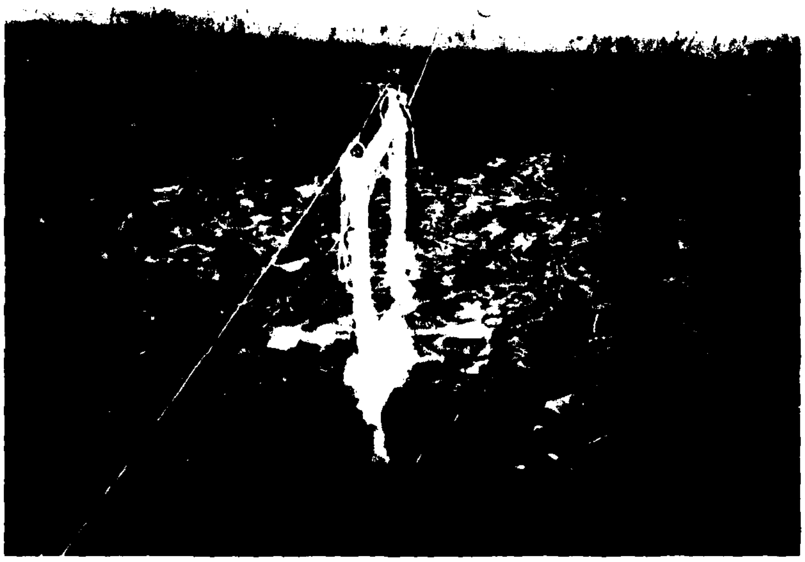

Figure 9. Polyvinyl chloride pipe support structure in sump; the two element driven dipole array is visible near the water surface

Figure 10. Dipole array rotated through the vertical plane using a cable and counterweight assembly. The counterweight and attached cable are shown on the left end of the antenna boom and the dipole array on the right end

estimating the vertical angle. As an example of the magnitude of the resulting error (at vertical angles $\pm$ 15 deg of the horizontal), consider a tag located 10 m from the antenna at an angle of 5 deg below the horizontal with the antenna located 1 m below the water surface. According to Equation 5, the depth of the fish would be 1.87 m. If the range can be estimated no better than $\pm$ 2 m, then R in Equation 5 could vary from 8 to 12 m; Equation 5 would then predict that the tag depth would be 1.70 or 2.05 m (with D_1 = 1 m and θ = 5 deg). If the error in the vertical angle is 5 deg, then θ in Equation 5 (with D_1 = 1 m and R = 10 m) could vary from 0 to 10 deg; the depth estimate would then vary from 1.0 to 2.74 m. Obviously, greater error is introduced into the depth estimate due to the error in determining the vertical angle than in estimating the distance between the antenna and the tag (for vertical angles close to the horizontal).

The system that has been developed thus far is not practical for field use due to its limited working range between the antenna and the tag (in this case 8 to 13 m) and because of the error in estimating the vertical angle; however, the testing at WES has shown that this approach is a practical method to locate the depth of a radiotagged fish. Classical antenna theory indicates that even under free-space conditions the basic two element driven dipole array has a broad radiation pattern (3 db down at $\pm$ 60 deg of the major radiation lobe center line); thus,

the problems experienced with the distortion of the radiation pattern should be anticipated. Obviously, the next step toward developing a working field system to estimate the depth of a radiotagged fish is to fabricate an antenna that is relatively insensitive to radiation reflected from the media interfaces above and below the antenna, and an antenna which has a narrower major radiation lobe.

LARGE-SCALE OPERATIONS MANAGEMENT TEST

An Update on Radio Telemetry Tracking of the White Amur, Lake Conway, Florida*

by

Jeffrey D. Schardt** and Larry E. Nall†

Introduction

During the LSOMT conducted at Lake Conway, Florida, the effect of the white amur on vegetation has been studied for three years (Schardt and Nall 1980). By the end of the second poststocking year, definite declines in the vegetation were noted. At that time WES scientists decided a correlation between vegetation declines and fish presence would be desirable and initiated a study to determine the feasibility of using radio telemetry techniques in Lake Conway. The study reviewed various types of equipment and concluded that a fish tracking study should be included in the Lake Conway project.

In order to conduct the fish tracking study, understanding of white amur behavior was needed in the following areas:

a. Movement, if any, during feeding.

b. Relationships between water temperature and feeding activity.

c. Preference for food type.

d. Preference for specific areas.

e. Diurnal activity variance.

f. Preference for depth.

g. Interchange among pools.

h. Variability among individual behavior.

i. Gregarity among individuals.

Feeding activity was assumed by correlating fish presence over particular vegetation types for extended periods. Analysis of stomach contents was necessary to confirm actual feeding and the species consumed.

Background information and preliminary results were presented in November 1979 (Nall and Schardt 1980). The paper presented herein

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* This paper was not presented at the 15th Annual Meeting but is included here for information purposes.

** Florida Department of Natural Resources, Orlando, Florida.

† Florida Department of Natural Resources, Bureau of Aquatic Plant Research and Control, Tallahassee, Florida.

updates radiotag implantation techniques and performance and summarizes the results of the first 18 months of radio tracking of white amur in Lake Conway.

Methodology

Implantation

The fish used for the implanting procedure were obtained from other lakes and ponds using rotenone (a fish toxicant) removal techniques which are most effective on the white amur (Colle et al. 1978). Only female fish of weights approximating those in the lake were tagged. A temporary holding facility was constructed to retain fish before the implanting procedure. The facility used 1200-ℓ holding tanks and a lake water flow-through system.

A V-shaped surgical trough was constructed to hold the fish ventral side upward with the gills submersed in an 80-ℓ aquarium. The fish were initially anesthetized in a 4 ppm quinaldine solution to aid handling. Quinaldine concentrations for anesthetization of fish ranged between 4 and 15 ppm. Five millilitres of 2 percent xylocaine (a local anesthetic) were injected into the incision site which allowed less quinaldine to be used and decreased fish recovery time.

Two to three rows of scales were removed around the incision site. A 5- to 7-cm incision was made vertically just anterior to the pelvic fin girdle. The lower end of the incision stopped about 2 to 3 cm from the midventral line. This incision site was chosen because the radiotag and viscera might place a strain on sutures in a longitudinal midventral incision which could cause the wound to reopen (Crumpton et al. 1978). This hypothesis was tested and did occur. Radiotags were inserted into the abdominal cavity and positioned at the lowest point. All instruments and radiotags were soaked in alcohol before use but no further attempt at sterility was made. All fish were confirmed to be female by the presence of eggs.

Closure was initially accomplished using 000 Type C Chromic Gut suture material. Four to six deep stitches were made through the body wall using a 6 D half circle cutting suture needle. Five to seven shallower stitches were made through the epidermis using a smaller 8 D half circle cutting needle which ensured a tight closure. Approximately 25 percent of the transmitters were rejected within 2 months after stocking. This was thought to be caused by dissolvable suture material breaking down before the wound had sufficiently healed. In December 1979, nine fish were implanted with tags and put into a holding pond. Six were closed with Chromic Gut and three with 000 Type B Black Braided Silk. When the fish were removed 30 days later, those closed with silk had nearly healed. Only three Chromic Gut closures held. Two of the remaining fish died from the open wounds. Seventy-five millilitres of water was drained from the body cavity of the third; it was then resutured with silk and released. All future closures will use braided silk.

After closure, 10 ml of injectable terramycin solution, which contains 50 mg/ml oxytetracycline hydrochloride, was administered intramuscularly. This was a dosage of approximately 55 mg oxytetracycline per kilogram of body weight. Intraperitoneal injections and antibiotic ointment applied directly to the incision were considered but rejected because of a suggestion that this might prematurely dissolve the suture material. It was also suggested by some that intramuscular injections of terramycin might cause large lesions around the injection area. Six of the nine fish implanted in December 1979 were injected intramuscularly, four with terramycin and two with chloramphenicol; none showed lesions after 30 days.

Analysis

Results were interpreted by comparing fish location maps with depth and plant distribution maps. A SAS computer program was developed which plots fish coordinates and compares them with vegetation and depth (SAS Institute Inc. 1979). The program also calculates distance traveled and times elapsed between sightings.

Results and Discussion

Radio equipment

The radiotags used during the project performed poorly. Only eight of twenty-eight tags remained functional after 18 months (Table 1). AVM Instrument Company rated the tag design life at a maximum of 58 months. The problem could have been with housing design rather than electronic breakdown. Upon recovery of two transmitters from dead fish (#30 and #60), small cracks were noted in the epoxy covering the bases of the loop antennae. Amur are extremely powerful fish. The tags are placed against the musculature in the body cavity. A quick movement by a startled fish could snap the fragile covering over the antenna wire and allow water entry into the electronic components. Twenty-five new radiotags will arrive in November 1980 from the Wildlife Materials Company. All have been ordered with the antenna strengthened and the covering improved.

Implantation

A total of 27 implanted fish have been released into Lake Conway as of October 1980. The first ten radiotags were implanted on May 2 and were released after 24 hr of observation. Two of the fish died within 11 months. The recovered tags failed before they could be reimplanted. Within eight months after stocking, five tags failed while still in the fish. Two trackable fish remain from the May 1979 release. Thirty fish were obtained in Fort Lauderdale on 7 and 9 August 1979, and transported to Lake Conway for implantation on 10 August. Exceptional stress from capture and transportation in mid-summer temperatures caused many of these fish to die prior to surgery. Only ten fish in fair condition were released. Three soon died and the tags were recovered, but two

failed before they could be reimplanted. Seven tags failed while in the fish. Of the August group, only one transmitter remains functioning. Six fish were released on 18 January 1980. Cooler temperatures and the improved surgical techniques discussed earlier allowed for better survival than in August. One fish was resutured and then was held 1 month for recovery. Its tag failed 2 months after restocking. Two more tag failures occurred in late September leaving only five presently functioning.

Observations

Tracking data were collected for 17 months as of September 1980. Only one fish, #3, was tracked the entire period because of difficulties with the tags and surgical procedures. Two fish were tracked for a full year. Only seasonal data could be collected for the remaining amur. A total of 1484 sightings have been made.

The amur exhibited a home range. Fish #26 (Figure 1) is representative of seven of nine fish which were tracked more than 6 months. This fish remained at the junction of East and West Pools in a large population of nitella (*Nitella megacarpa*), a preferred species, but occasionally moved as far away as 1 km. Fish #23 (Figure 2) was located in the shallow water of East Pool in populations of nitella and pondweed (*Potamogeton illinoensis*), another preferred species. Fish #23 was found away from this area only seven times. Fish #34 (Figure 3) frequents two areas in East and West Pools and crossed between them six times. In order to move from one range to the other the fish had to cross several stands of nitella and pondweed, but it did not settle in any of these areas. Fish #3 (Figure 4), which has crossed South Pool thirty-five times, does not exhibit a home range and seems to be limited only by the extent of vegetation. Only one other fish tracked, #13, demonstrated this large range of movement. Once a range has been established, the fish remain in the region until the preferred vegetation is eradicated. Divers have observed progressive clearing of nitella beds during monthly underwater inspections. Fecal deposits containing nitella were also found in the cleared zones.

None of the implanted fish crossed from South or East Pool into Middle Pool during the study. The shallow, narrow canals connecting these pools may sufficiently restrict travel between the pools. Also, the nitella coverage in South Pool during that tracking period ranged from 28 to 58 percent (Schardt and Nall 1980). This was probably enough vegetation to keep the fish within the pool. However, tagged fish routinely crossed between East and West Pools. This opening is 4 m deep and about 50 m across, and apparently not restrictive to passage (Figures 5 and 6). Eelgrass (*Vallisneria americana*), a nonpreferred food, was the dominant plant in East and West Pool (Schardt and Nall 1980). Presumably, the fish are in search of preferred vegetation. Passage through the narrow canals may begin to occur as the vegetation becomes increasingly rare.

No seasonal differences in movement and depth were observed (Tables 2 and 3). Fish remained in the same depths (Figures 5 and 6) and in vegetation (Figures 7 and 8) throughout the year.

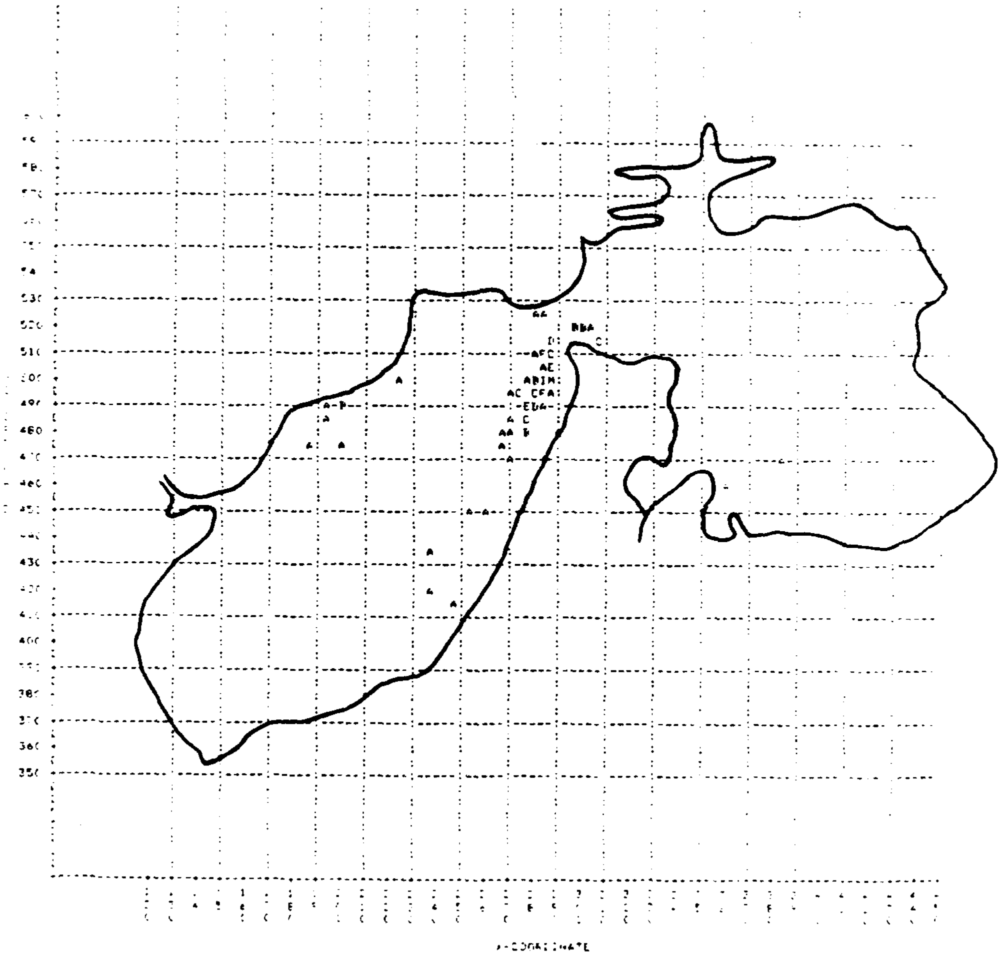


Figure 1. Cumulative sightings of fish #26, East and West Pools. A = one observation, B = two observations, etc.

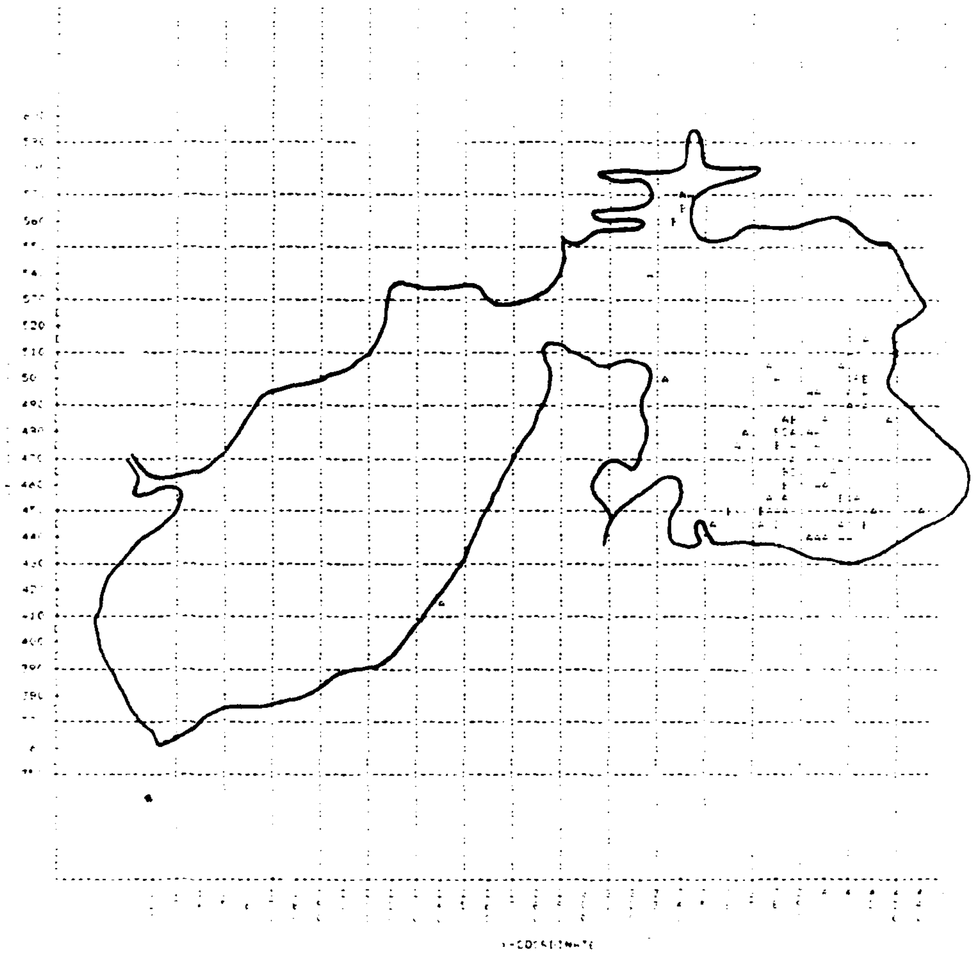


Figure 2. Cumulative sightings of fish #23, East and West Pools. A = one observation, B = two observations, etc.

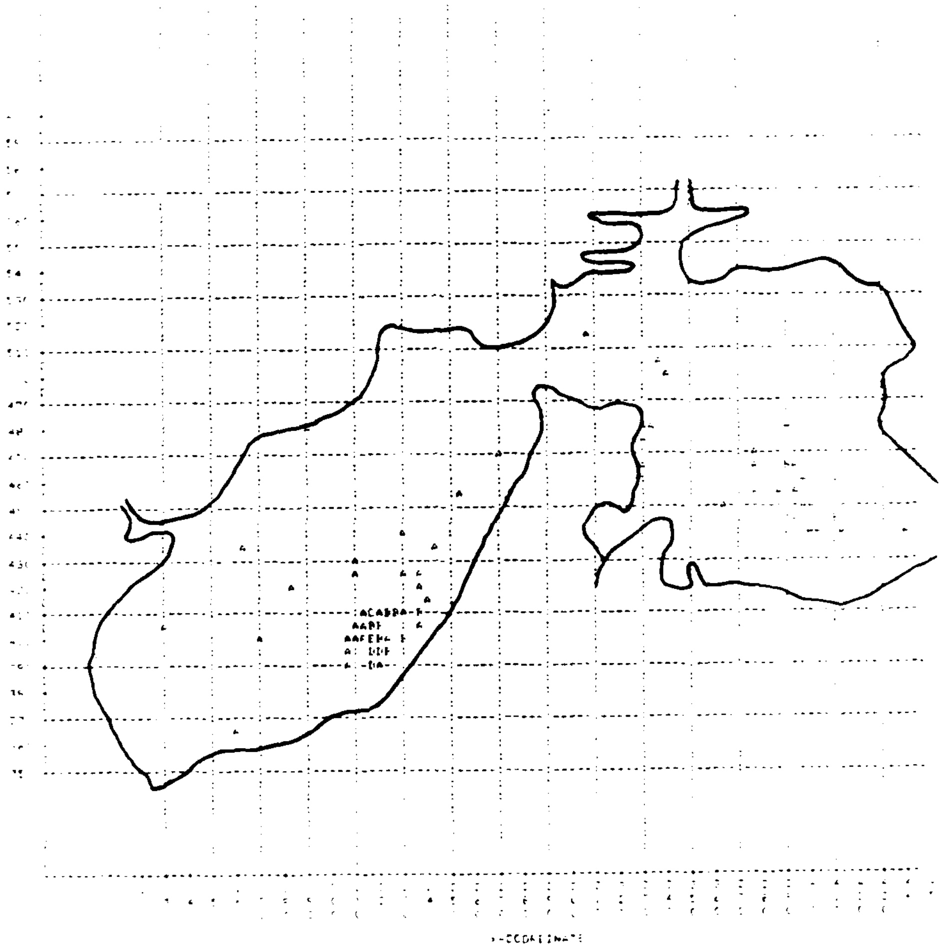


Figure 3. Cumulative sightings of fish #34, East and West Pools. A = one observation, B = two observations, etc.

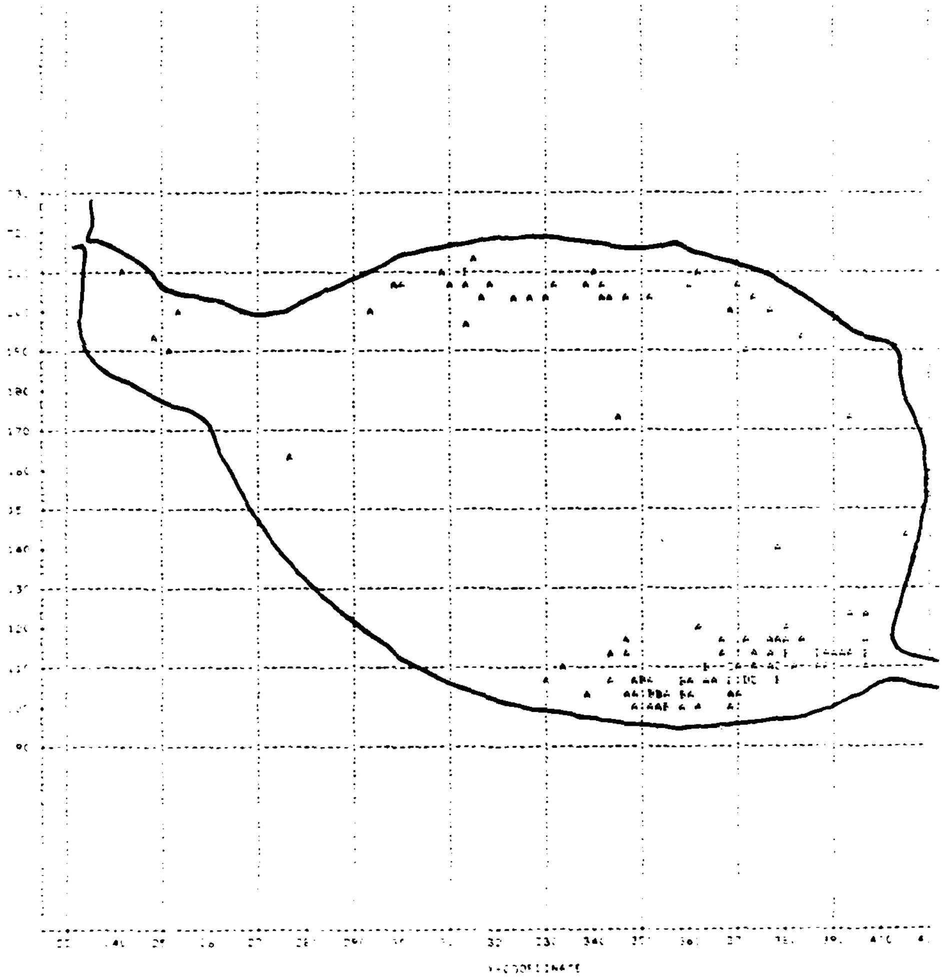
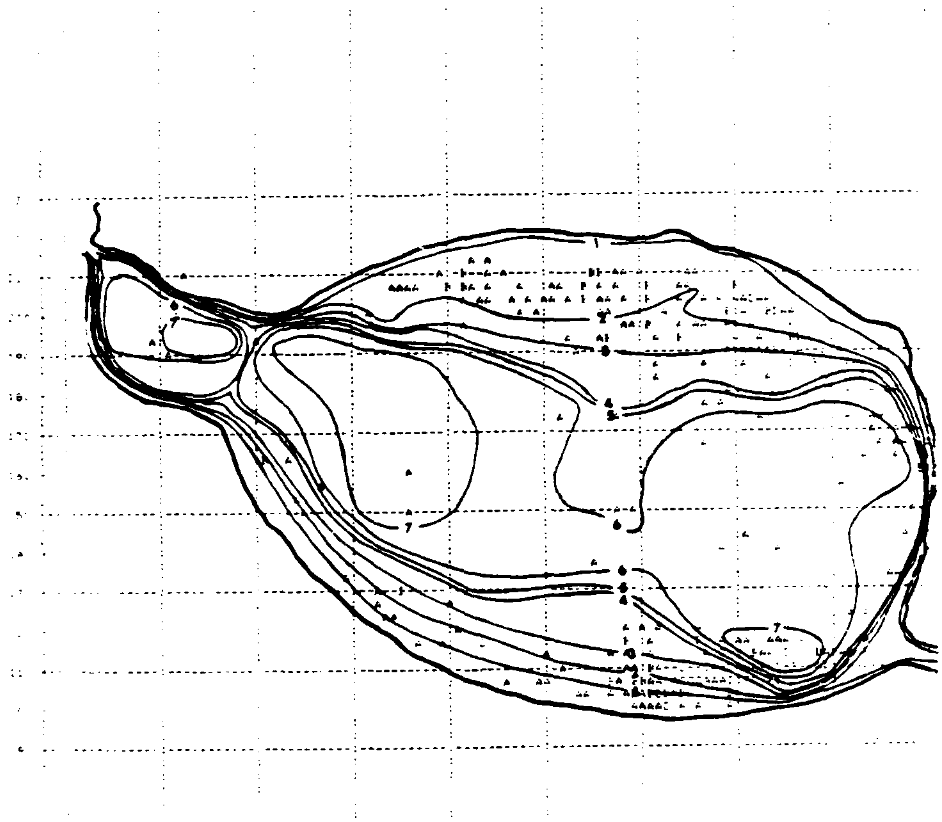


Figure 4. Cumulative sightings of fish #3, South Pool.
A = one observation, B = two observations, etc.



Depth in meters

Figure 5. Cumulative sightings for South Pool. A = one observation, B = two observations, etc.

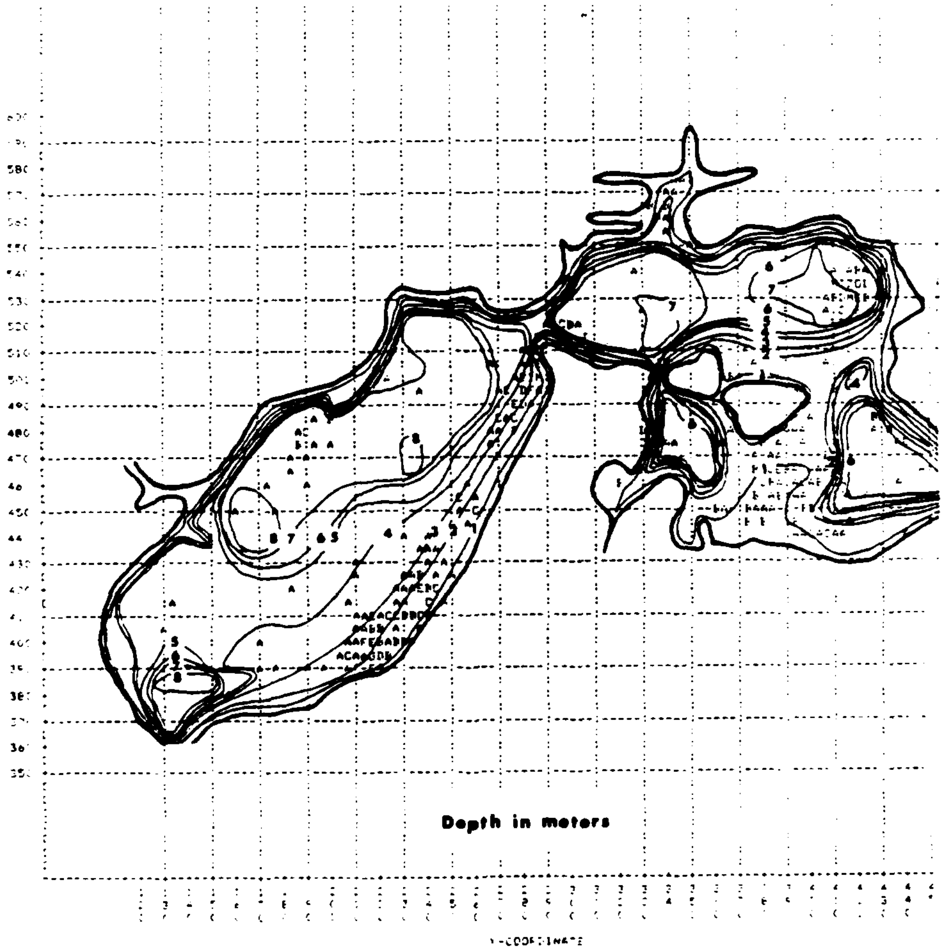


Figure 6. Cumulative sightings for East and West Pools.
A = one observation, B = two observations, etc.

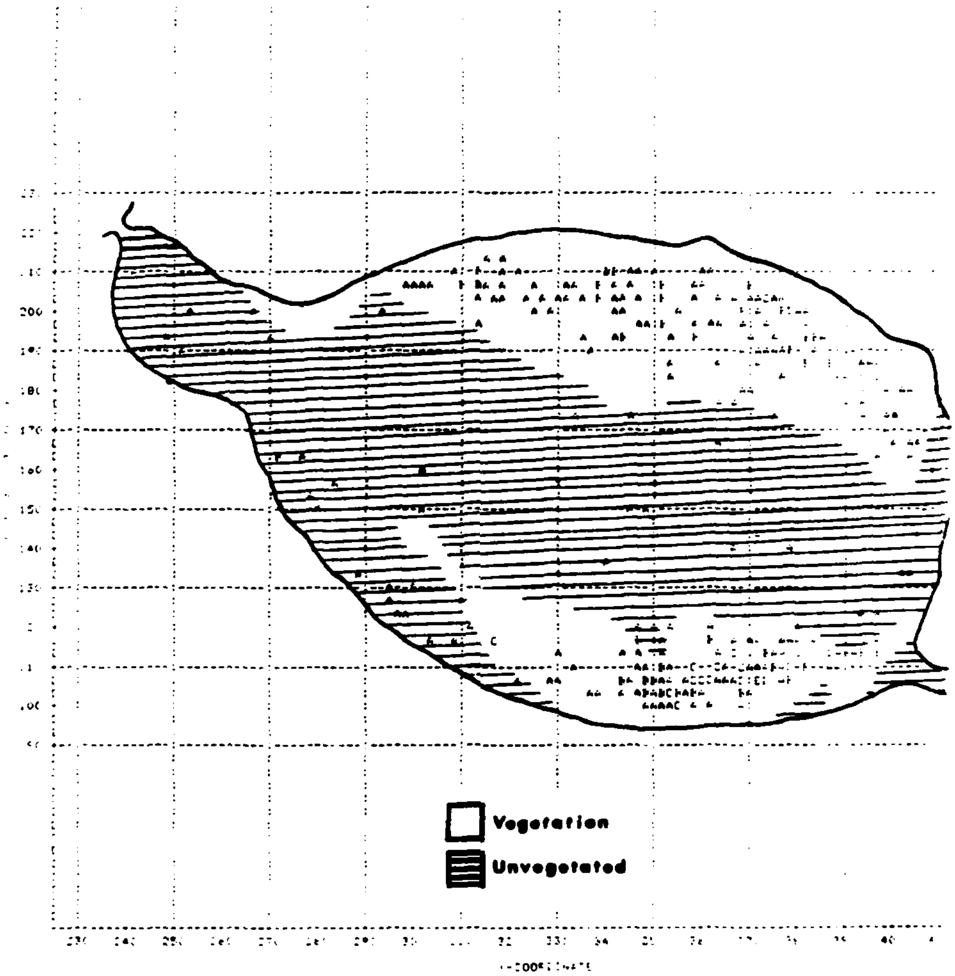


Figure 7. Cumulative sightings for South Pool.
A = one observation, B = two observations, etc.

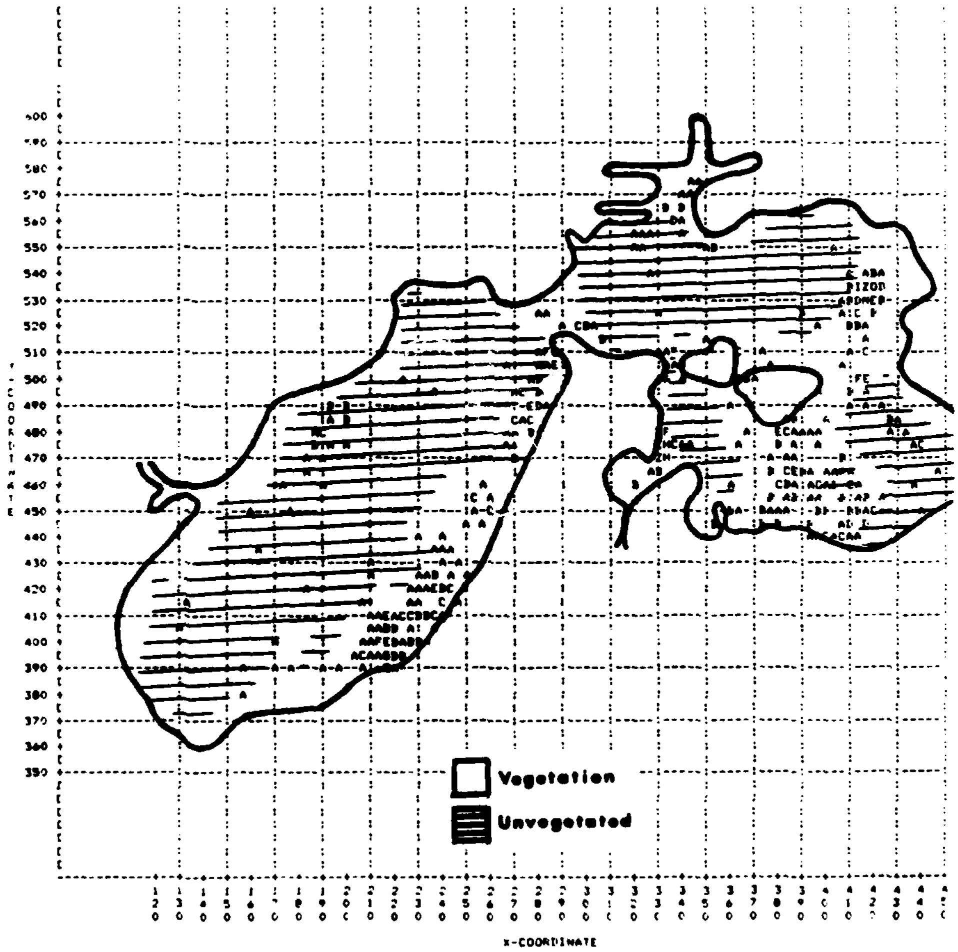


Figure 8. Cumulative sightings for East and West Pools.
A = one observation, B = two observations, etc.

Chi-square analysis showed a significant preference ($P < 0.0001$) for vegetation in less than 3 m of water (Figures 5-8). Eighty-eight percent of the fish tracked were located in vegetation (Tables 2 and 4). The number of nonvegetated sightings approached vegetated sightings only during August and September (Table 2). Ninty-three percent of the 1484 sightings were in 3 m of water or less (Table 3). This was also significant ($P < 0.0001$).

The telemetry project started too late to test for a preference for hydrilla (*Hydrilla verticillata*). Implanted fish were stocked beginning in May 1979. Five months after stocking, hydrilla was collected only in trace quantities on transects and plots. The fish are most often associated with pondweed and nitella. Although several fish have been in areas with mixed vegetation, plant surveys showed that eelgrass populations were unchanged as nitella and pondweed declined (Schardt and Nall 1980).

Tagged fish were often observed swimming in schools of approximately 30 untagged fish. Therefore, tagged fish movement is presumed to be similar to that of the untagged population. The possibility that so many fish would gather by chance is unlikely since vegetation is still abundant in many areas of the lake. Currently, one tagged fish remains in South Pool and four in East and West Pools. In the future, equal numbers of tagged fish will be released among South, West, and East Pools. Futher evidence of tagged and untagged fish associations may allow for more definitive conclusions on gregarious behavior among the amur.

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Acknowledgements

This work was supported by Contract No. DACW39-76-C-0084 from the U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi. The authors would like to thank Ms. Gail M. Sloane, Mr. Barry D. Billets, and Mr. Gregory P. Jubinsky for their technical field assistance.

Table 1

Radiotag Characteristics

Fish#	Pool	Date Implanted	Radiotag Failure	Radiotag Life, days
1	South	5/03/79	5/09/80	362
2	South	5/03/79	10/05/79	155
3	South	5/03/79		
4	South	5/04/79	5/12/80	376
5	South	5/04/79	1/30/80	272
6	South	5/04/79	10/05/80	154
7	South	5/04/79	10/06/79	155
8	Middle	5/05/79		
9	Middle	5/05/79	8/17/79	104
10	Middle	5/05/79	12/16/79	225
11	South	8/10/79	12/10/79	122
13	South	8/10/79		
14	East	8/10/79	8/16/79	6
17	East	8/10/79	8/17/79	7
18	East	8/10/79	8/18/79	8
19	East	8/10/79	5/09/80	277
20	East	8/10/79	8/25/79	15
23	West	8/11/79	9/19/80	406
25	West	8/11/79	1/07/80	151
26	West	8/11/79	9/26/80	414
28	South	12/18/79	4/04/80	108
29	South	12/18/79	4/04/80	108
30				
31	East	12/18/79		
32	West	12/18/79	9/25/80	282
33	East	12/18/79		
34	West	12/18/79		
60				

Table 2

Collective Sighting by Month for Vegetated Area and Water Depth (5-15-79 through 10-15-80)

Month	% Nonvegetated	% Vegetated	Average Water Depth, m
Jan	2	98	1.82
Feb	2	98	2.07
Mar	15	85	2.93
Apr	4	96	1.97
May	1	99	2.17
Jun	0	100	2.71
July	9	91	2.24
Aug	35	65	2.29
Sep	42	58	2.23
Oct	2	98	1.58
Nov	0	100	1.18
Dec	0	100	1.40

Table 3

Percent Sightings by Month and Water Depth (5-15-79 through 10-15-80)

Month	Water Depth, m 1	2	3	4	5	6	7	Total Number
Jan	39	43	11	5	1	0	0	217
Feb	31	37	23	3	6	0	0	95
Mar	13	34	30	9	3	6	5	101
Apr	39	45	2	4	7	3	0	109
May	30	34	20	6	4	5	1	141
Jun	14	45	18	13	4	3	3	95
July	22	47	18	5	3	4	1	224
Aug	31	37	19	5	2	4	2	156
Sep	24	43	23	5	3	1	1	102
Oct	41	45	9	2	2	1	0	133
Nov	67	33	0	0	0	0	0	49
Dec	58	39	2	2	0	0	0	62
								1484

Table 4

Individual Fish Sightings* by Vegetated and Nonvegetated Areas and Water Depth (5-15-79 through 10-15-80)

Fish#	Sightings	% Nonvegetated	% Vegetated	Average Water Depth, m
1	28	4	96	1.9
2	26	4	96	1.7
3	163	4	96	1.8
4	90	1	99	1.7
5	77	3	97	1.7
6	17	6	94	2.1
7	17	6	94	1.6
13	119	26	74	2.4
23	121	12	88	2.1
25	40	2	98	1.4
26	141	6	94	2.3
28	38	29	71	3.0
29	45	0	100	2.0
30	134	19	81	1.7
31	76	8	92	2.9
32	137	1	99	2.0
24	126	26	74	2.2
TOTAL	1395			

* Only fish with more than 10 sightings are listed.

LARGE-SCALE OPERATIONS MANAGEMENT TEST

Monitoring and Fragment Barriers in Eurasian Watermilfoil Growth Prevention

by

E. A. Dardeau, Jr.*

Introduction

In cooperation with the U. S. Army Engineer District, Seattle (NPS), WES has initiated a Large-Scale Operations Management Test (LSOMT) to evaluate the concept of prevention as an operational technique for managing problem aquatic macrophytes in the State of Washington. The primary objective of the LSOMT is to prevent the submersed aquatic macrophyte, Eurasian watermilfoil (*Myriophyllum spicatum* L.), from reaching problem-level proportions in selected water bodies within that state.** Eurasian watermilfoil, a member of the plant family Haloragaceae, was first introduced into North America in the nineteenth century. Since 1960 it has rapidly spread across North America and has reached problem levels in most water bodies where it has become established.† Its broad ecological amplitude has enabled it to adapt well to spring, fluvial, lacustrine, and estuarine ecosystems in the United States and Canada.

Large-Scale Operations Management Test

The WES developed an LSOMT designed to provide the data that would result in the identification of prevention methodologies that can be implemented to prevent Eurasian watermilfoil from reaching problem-level proportions. Component plans of the LSOMT were developed to include the following elements:

a. Test Site Selection Plan.

b. Monitoring (Surveying) Plan.

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* U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

** U. S. Army Engineer Waterways Experiment Station, CE (WES). 1979. "Large-Scale Operations Management Test to Evaluate Prevention Methodology," Work Statement, Vicksburg, Miss.

† Elser, H. J. 1969. "Observations on the Decline of the Watermilfoil and Other Aquatic Plants, Maryland, 1962-1967," Hyacinth Control Journal, Vol 8, No. 1, pp 52-60.

c. Reporting Plan.

d. Treatment Plan.

e. Public Awareness Plan.

f. Training Plan.

This paper focuses on the monitoring and treatment aspects of the LSOMT. It covers the development and analysis of the monitoring procedures used and the effectiveness of a barrier constructed to intercept fragments of Eurasian watermilfoil.

Monitoring and Treatment Efforts

The NPS selected 13 water bodies in the State of Washington for evaluation as candidate test sites. Through joint NPS-WES coordination, the five test sites shown in Figure 1 were selected, based on the following criteria: (a) presence of Eurasian watermilfoil; (b) encompassing

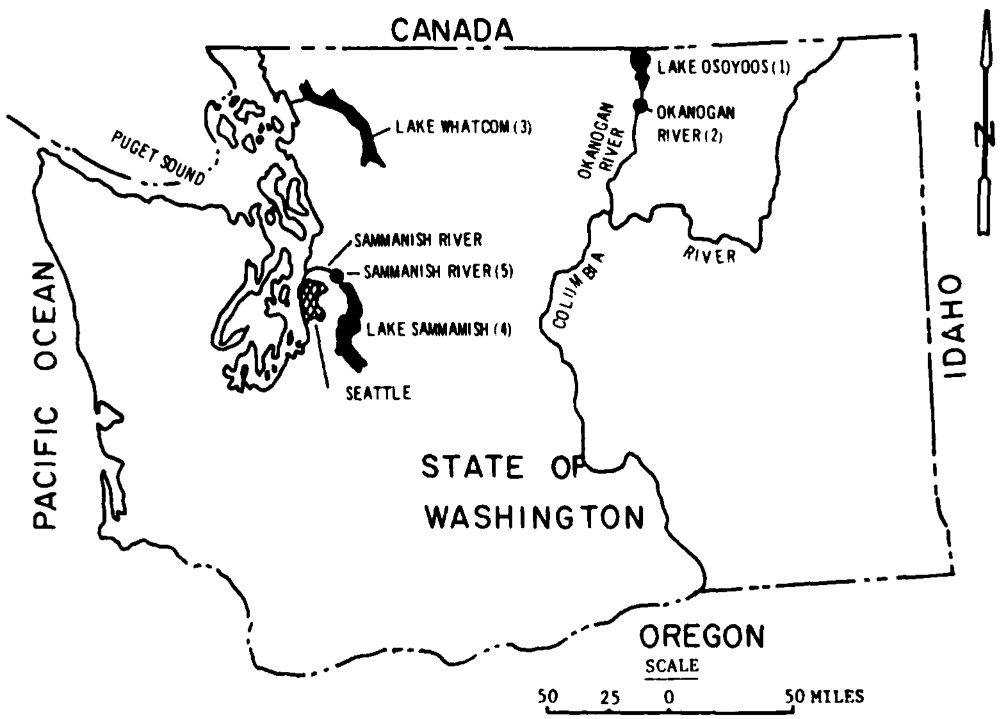

Figure 1. Locations of test sites on Lake Osoyoos, Okanogan River, Lake Whatcom, Lake Sammamish, and Sammamish River in the State of Washington

both fluvial and lacustrine ecosystems; (c) encompassing a typical range of environmental conditions found in eastern and western Washington; and (d) encompassing Category I, II, and III designations as follows:

a. Category I (Prevention). Areas with few or no problem-level populations of Eurasian watermilfoil that are in close proximity to documented populations and are, therefore, vulnerable to expanded population growth.

b. Category II (Maintenance). Areas with small problem-level populations of Eurasian watermilfoil and with large areas of potential habitat.

c. Category III (Control). Areas with extensive populations that significantly impact on user interests.

The test sites chosen were:

a. Lake Osoyoos - located on the United States-Canadian border in Okanogan County, Washington, and in British Columbia. It is a 5729-acre (2036 acres in the United States) natural lake on the Okanogan* River (Okanogan River Miles 79.0-90.0, with Mile 82.5 being the international boundary), a right-bank tributary of the Columbia River. Category I (Prevention).

b. Okanogan River - also located in Okanogan County. The test site is a selected reach between Zosel Milldam (Mile 77.4) and the downstream end of Lake Osoyoos (Mile 79.0). Category I (Prevention).

c. Lake Whatcom - a 5029-acre natural lake located in Whatcom County. Serves as the principal water supply for the City of Bellingham. Category II (Maintenance).

d. Lake Sammamish - a 4897-acre natural lake located approximately 13 miles east of Seattle, in King County. Category III (Control).

e. Sammamish River - also located in King County. Outlet of Lake Sammamish that drains directly into Lake Washington. Reach that encompasses the test site extends from the Lake Sammamish outlet (Mile 15.3) downstream to the highway overpass at Marymoor Park (Mile 14.4). Category II (Maintenance).

Monitoring

The monitoring effort consisted of both remote sensing surveys and ground truth data collection. Both phases are discussed.

Remote sensing surveys. In the summer and early fall of 1979, NPS and the WES scheduled remote sensing missions to map the areal extent of Eurasian watermilfoil populations at each of the three lacustrine test sites. These missions, which ranged from partial to complete test site

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* This river is spelled "Okanagan" in Canada.

coverage, were flown using black and white (Kodak Double-X Aerographic, 2406; Zeiss A filter), color (Kodak Ektachrome EF Aerographic, SO397; no filter), and color infrared (Kodak Aerochrome Infrared, 2443; Zeiss R filter) film at scales of 1:5000, 1:10,000, and 1:20,000. A set of each type of imagery was given to a skilled interpreter (not familiar with these lakes), who determined area occupied by Eurasian watermilfoil colonies. Table 1 shows the total infested area computations using a single scale for each type of imagery for Lake Osoyoos, Lake Whatcom, and Lake Sammamish. Based on field verification, areas determined with 1:5000-scale color imagery were more accurate than those determined with other scale-imagery combinations.

The next phase involved the determination of the area occupied by a representative "topped-out" colony that appeared on all types of imagery at all scales. Table 2 shows the results of this detection effort, and it also illustrates the difficulty in mapping submersed aquatic vegetation without the benefit of ground truth data. Areas determined on 1:5000-scale color imagery were most accurate when later field checked. The interpreter was most confident in the interpretations he made using this scale-imagery combination. Variations in area are attributable, in part, to the water-penetration capability of the various films tested; however, differences in site conditions at the time of overflight also affected the ability to accurately detect the areal extent of these populations.

Many areas that appeared to contain submersed aquatic vegetation were tentatively marked but had to be field checked for verification of the presence of Eurasian watermilfoil. Often areas of dead organic material were confused with the colonies of the problem species. Remote imagery did, however, adequately serve as the basis for selecting sites for the ground truth surveys in this study.

Ground truth data collection. With the help of professional divers, the WES established the maximum-observed depth (MOD) at which Eurasian watermilfoil occurred in Lake Osoyoos, Lake Whatcom, and Lake Sammamish. The contours for the MOD in each lake were then transferred from existing hydrographic surveys to maps and aerial imagery so that estimates of potential infestable acreage could be obtained. Below are the MOD's and potential Eurasian watermilfoil habitat for each site:

Lacustrine Test Site	MOD, ft	Potential Habitat acres
Lake Osoyoos	25	425*
Lake Whatcom	25	506
Lake Sammamish	35	928

* Does not include the Canadian portion of the lake.

Although areal maps and images are useful in establishing colony locations and determining changes in configurations of colony boundaries over time, they do not provide information on colony density or the

amount of vegetative material present in a plant population. The WES approached the problem by attempting to characterize the aquatic plant populations of Lakes Osoyoos, Whatcom, and Sammamish in terms of their biomass. Maps and remote imagery of Lakes Osoyoos, Whatcom, and Sammamish, on which the MOD's had been plotted, were overlaid with grids, and grid squares were selected at random inside each MOD for each lake. The WES field teams then used the WES Biomass Sampler to sample all the randomly selected grid squares. This sampler collected aquatic vegetative material inside a 2.69-ft^2 column that extended from the surface of the water to the lake bottom. Team members measured depths, identified all plants, made wet weight determinations, and counted meristems with each sample.

The biomass values for the random grid squares were then used to compute the biomass of Eurasian watermilfoil in the three water bodies. Following are the unit and total biomass values that were determined for Lake Osoyoos, Lake Whatcom, and Lake Sammamish:

Lacustrine Test Site	Unit Biomass lb/acre	Total Biomass lb
Lake Osoyoos*	147.4	62,629
Lake Whatcom	73.2	37,026
Lake Sammamish	45,432.7	4,130,287

* Does not include the Canadian portion of the lake.

Determinations of biomass density (i.e., wet weight/unit volume) were then made using the wet weights collected in each 2.69-ft^2 column of water and the sample volumes (i.e., cross-sectional area × depth of sample). Table 3 shows the ranges of biomass and biomass density values for the grid squares containing Eurasian watermilfoil in each lake.

Treatment

In late July 1979, the NPS constructed a barrier system consisting of debris, operational, and evaluation barriers across a 290-ft-wide cross section of the Okanogan River, 0.1 mile downstream from the Cherry Street Bridge at Oroville, Washington (Mile 77.9). Cost (1979) for design, construction, operation, and maintenance was $95,000. This system was operated for a 12-week period until mid-October of that year. Below is a description of the three barriers:

a. Debris barrier. A 2-in. mesh barrier designed to intercept large floating debris (e.g., logs) upstream from the operational barrier. Extends bank to bank from slightly above the water surface to within 3 ft of the streambed (to permit migration of anadromous fishes).

b. Operational barrier. Originally a 0.5-in. mesh structure (borrowed from the British Columbia Ministry of the Environment), later replaced by a 0.375-in. structure intended to

collect fragments of Eurasian watermilfoil. The top of this barrier is placed in the same position (with respect to the water surface) as the debris barrier and has approximately the same dimensions.

c. Evaluation barriers. Two barriers, each having five sets of six vertically arranged 1-ft-square net sections, that extend from slightly above the elevation of the water surface to the elevation of the streambed. One evaluation barrier (No. 1) was placed upstream from, and the other (No. 2) downstream from, the debris and operational barriers. These evaluation barriers were designed to evaluate the effectiveness of the operational barrier at removing Eurasian watermilfoil fragments from a water body.

A contractor collected wet weights of the vegetative material on the operational barrier twice each week and determined average weekly percentages of Eurasian watermilfoil from several representative samples. Total wet weight of vegetative material declined but the percentage of Eurasian watermilfoil found in the samples increased each week. During the first week (29 July-4 August), the height of the growing season, only 5.2 percent (by wet weight) of the total quantity of vegetative material collected was Eurasian watermilfoil, whereas in the twelfth week (14-20 October), when fragmentation was in progress, the percentage had reached 34.8 (Figure 2).

The evaluation barriers were in place for 11 weeks, their last week of operation being 7-13 October 1979. Evaluation Barrier No. 1 served as the control for the experiment. An overwhelming majority of the material collected on Evaluation Barrier No. 1 was intercepted on the net sections sampling the 0- to 1-ft depth range. Although lesser total weights were collected each week on Evaluation Barrier No. 2, these weights had a more even vertical distribution, indicating that the operational barrier was performing as designed and that the river currents had carried some fragments beneath the operational barrier. Effectiveness values of the barrier system are shown graphically in Figure 3. Effectiveness values ranged from a low of 23.6 percent during week No. 7 (9-15 September) to a high of 86.1 percent during week No. 5 (26 August-1 September). The average weekly effectiveness was 62.2 percent.

During FY 80 no provision has been made for evaluation barriers; therefore, effectiveness will no longer be measured. A contractor will, however, clean the barrier twice weekly. With the present improved design, he is better able to adjust the angle of the barrier screens so that the top edge leans slightly more upstream, thus providing for a more efficient operation. The angle of the barrier screen has to be adjusted with the streamflows, which are normally low during the time of barrier operation.

Literature on fragment barriers was examined by personnel at WES who found that the British Columbia Ministry of the Environment had constructed several plant fragment barriers in the Canadian portion of

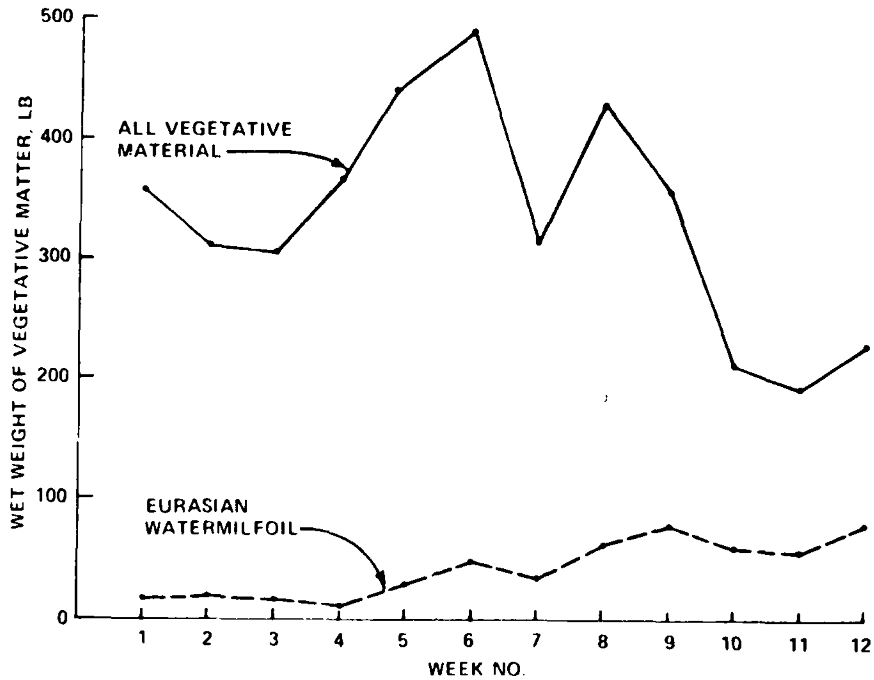

Figure 2. Wet weights of Eurasian watrmilfoil and of all vegetative material collected on operational fragment barrier, Okanogan River, Oroville, Washington, during the period 29 July-20 October 1979

the Okanagan River Basin. These barriers had reported effectiveness values ranging from 86 to 97 percent.* Closer examination of the method in which these values were determined showed that the Canadians had compared the weight of material collected on an upstream sampling cage (approximately equivalent to one set of the net sections of the NPS evaluation barrier) with that collected on the operational barrier during the same time periods. No provison had been made for a downstream evaluation barrier; therefore, true effectiveness had not been measured.

Conclusions

The fieldwork conducted under the auspices of the LSOMT in the State of Washington during FY 79 yielded some useful results. It was

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* British Columbia Ministry of the Environment, Water Investigations Branch. 1978. "British Columbia Aquatic Plant Mangement Program, Report on Aquatic Plant Fragment Barriers," Victoria, B. C., Canada.

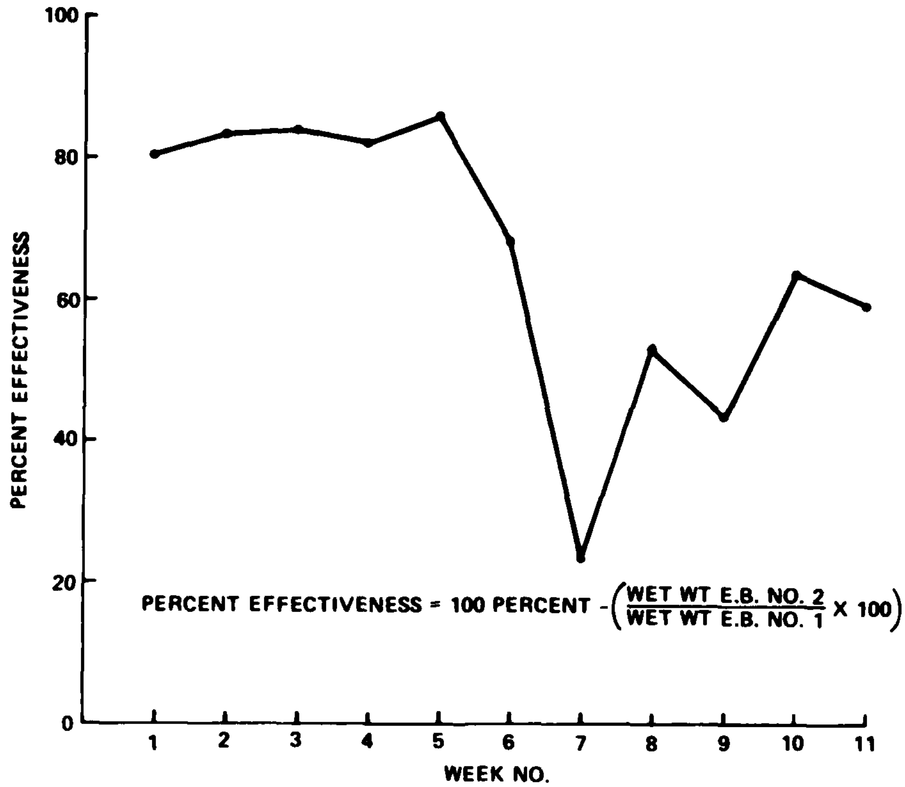

Figure 3. Percent effectiveness of operational fragment barrier, Okanogan River, Oroville, Washington, during the period 29 July-13 October 1979, based on wet weight of material collected on upstream (No. 1) and downstream (No. 2) evaluation barriers

determined that color aerial imagery proved to be superior to either black and white or color infrared for detection and mapping the areal extent of colonies of Eurasian watermilfoil. The results also indicated that the largest affordable scale (e.g., 1:5000) should be used because of the difficulty and the confusion involved in mapping a submersed flora at a small scale. It should again be emphasized that remote sensing data should be only supplemental to that collected by ground truth surveys in a prevention program. However, regardless of the aquatic plant management objective--whether prevention, maintenance, or control--field verification of photointerpretation is always necessary.

Ground truth surveys were used to establish the MOD for growth of Eurasian watermilfoil in Lakes Osoyoos, Whatcom, and Sammamish. These MOD's were then plotted on imagery and maps. Random biomass samples taken within the MOD's to characterize the aquatic flora showed that relatively few samples in Lakes Osoyoos and Whatcom contained Eurasian watermilfoil, while nearly one third of the samples collected in Lake

Sammamish contained this aquatic macrophyte. Biomass and biomass density values for the samples that contained this species indicated more wet weight of Eurasian watermilfoil per unit area and unit volume, respectively, for Lake Sammamish followed by Lake Osoyoos and Lake Whatcom. The WES Biomass Sampler proved to be a rapid and efficient means of sampling the vegetation in a water column.

The Okanogan River barrier installation averaged 62.2 percent efficiency during its 11-week period of operation, and the weight of Eurasian watermilfoil collected on the operational barrier increased each week due to fragmentation even though the total weight collected declined. The original barrier system had been borrowed from the British Columbia Ministry of the Environment. Later, the NPS replaced it with one of its own design, the major difference being a slightly smaller mesh size. The NPS has indicated that it is satisfied with the operation of the Eurasian watermilfoil fragment barrier.

Table 1

Total Area Occupied by Euraian Watermilfoil in Lake Osoyoos, Lake Whatcom, and Lake Sammamish as Interpreted from Three Types of Aerial Imagery

Test Site	Type of Imagery	Total Infested Area acres
Lake Osoyoos	Scale 1:10,000	
	Black and white	28*
	Color	22*
	Color infrared	33*
Lake Whatcom	Scale 1:10,000	
	Black and white	13
	Color	7
	Color infrared	4
Lake Sammamish	Scale 1:5000**	
	Black and white	3
	Scale 1:10,000	
	Color	11
	Color infrared	11

* Does not include Canada.
** No 1:10,000-scale black and white imagery available for Lake Sammamish.

Table 2

Detection of Single Representative Topped-Out Colonies of Eurasian Watermilfoil in Lake Osoyoos, Lake Whatcom, and Lake Sammamish Using Various Scale-Imagery Combinations

Test Site	Area, acres: Black and White	Color	Color Infrared
Lake Osoyoos		Scale 1:5000	
	11.2	9.8	11.1
		Scale 1:10,000	
	10.8	11.5	11.0
		Scale 1:20,000	
	12.1	12.1	13.4
Lake Whatcom		Scale 1:5000	
	0.9	2.1	1.0
		Scale 1:10,000	
	0.8	1.1	0.8
		Scale 1:20,000	
	1.3	1.9	1.3
Lake Sammamish		Scale 1:5000	
	0.9	1.2	0.7
		Scale 1:10,000	
	*	1.3	0.8
		Scale 1:20,000	
	*	1.9	1.9

* Black and white imagery of Lake Sammamish at scales of 1:10,000 and 1:20,000 not available.

Table 3

Biomass and Biomass Density Values for Eurasian Watermilfoil in Lake Osoyoos, Lake Whatcom, and Lake Sammamish

Test Site	Total No. of Samples Taken	No. of Samples Containing Eurasian Watermilfoil	No. of Samples Represented by Each Range of Values for Eurasian Watermilfoil						
			Biomass lb (wet weight)/ft^2			Biomass Density lb (wet weight)/ft^3			
			<0.01	0.01-<0.1	≥0.1	<0.001	0.001-<0.01	0.01-<0.1	≥0.1
Lake Osoyoos	145	11	8	2	1	5	4	2	
Lake Whatcom	146	12	11	1		7	5		
Lake Sammamish	96	31	15	8	8	12	8	10	1

LARGE-SCALE OPERATIONS MANAGEMENT TEST

Eurasian Watermilfoil Treatment With 2,4-D, Diquat, and Endothall at Reduced Application Rates

by

K. Jack Killgore*

Introduction

Background

In cooperation with the Seattle District (NPS), WES has initiated a Large-Scale Operations Management Test (LSOMT) to evaluate the concept of prevention as an operational technique for managing problem aquatic macrophytes in the NPS. The primary objective of the LSOMT is to prevent Eurasian watermilfoil (*Myriophyllum spicatum* L.) from reaching problem-level proportions in selected water bodies within the State of Washington.

Application rates

While effective chemical control techniques, using conventional herbicide formulations, have been developed and used to control watermilfoil, the application rates have been based primarily on the area of the infestation and the water volume. Application of herbicides in the aquatic environment has used the maximum allowable treatment rates to ensure control of the target plant rather than lower rates which could provide adequate control at greatly reduced costs and with less environmental damage.

Purpose and Scope

This research was designed to obtain minimum information on the degree and duration of Eurasian watermilfoil (milfoil) control using less than label-recommended herbicide application rates. The results will be used to recommend optimum chemical control techniques as part of an overall aquatic plant prevention program for NPS. The objectives of the study were:

a. To determine if selected reductions of the maximum label concentration of three conventional herbicides would control Eurasian watermilfoil.

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

b. To evaluate relative cost-effectiveness of the herbicide treatments.

Methods and Materials

Establishment of test plots and sample points

The site chosen to evaluate the prevention program in Washington was Lake Osoyoos. Lake Osoyoos is located on the United States-Canadian border in Okanogan County, Washington, and in British Columbia, Canada. It is a 2318-ha (821 ha in the United States) natural lake on the Okanogan River, a tributary of the Columbia River. The mean depth is 14 m with a maximum depth of 64 m. Lake Osoyoos has a small, nonproblem-level occurrence of Eurasian watermilfoil with large areas of potential infestable acreage. Because of the proximity of Lake Osoyoos to the Columbia River, and the ability of Eurasian watermilfoil to rapidly colonize once established in a drainage system, preventing the spread of Eurasian watermilfoil from Lake Osoyoos to the Columbia River is of operational interest to NPS.

Before implementing treatment procedures, an intense remote sensing survey was completed on Lake Osoyoos in 1979 to detect Eurasian watermilfoil colonies according to procedures described by Rekas (1979). Aerial color photographs at 1:5000 scale were used to outline boundaries of Eurasian watermilfoil colonies on base maps. A field survey of the lake was conducted in May 1980 to verify that outlined colonies were Eurasian watermilfoil and to tentatively select the treatment plots.

From the base maps, eight herbicide treatments and one reference plot were initially selected in Lake Osoyoos. Hydrodynamic patterns in these areas were examined using fluorescent dyes to ensure that cross-contamination between proposed treatment plots as well as drift of herbicides into water intakes could be avoided. In addition, an anemographic station was established on the eastern shoreline to aid in evaluating wind patterns that might be associated with water currents. Final determination of plot locations and sizes was made based on these preliminary evaluations of hydrological and meteorological data and the size and location of Eurasian watermilfoil colonies. Plots were approximately 0.4 ha in size, in water 1 to 5 m deep. Five plots for treatment with endothall (7-oxabicyclo-(2.2.1)-heptane-2, 3-dicarboxylic acid), 2,4-D DMA and BEE (2,4-dichlorophenoxyacetic acid liquid and granular, respectively), diquat (1,1-ethylene-2, 2-dipyridinium dibromide), as well as one reference plot were selected (Figure 1).

The morphometry of each plot was established using an Agricultural Navigator (AgNaV) and a Texas Instruments (TI) 59 programmable calculator with printer. The AgNaV facilitated precise enough positioning over milfoil beds that each initial sampling point could again be found during successive sampling periods (Rekas 1980). Programs were developed for

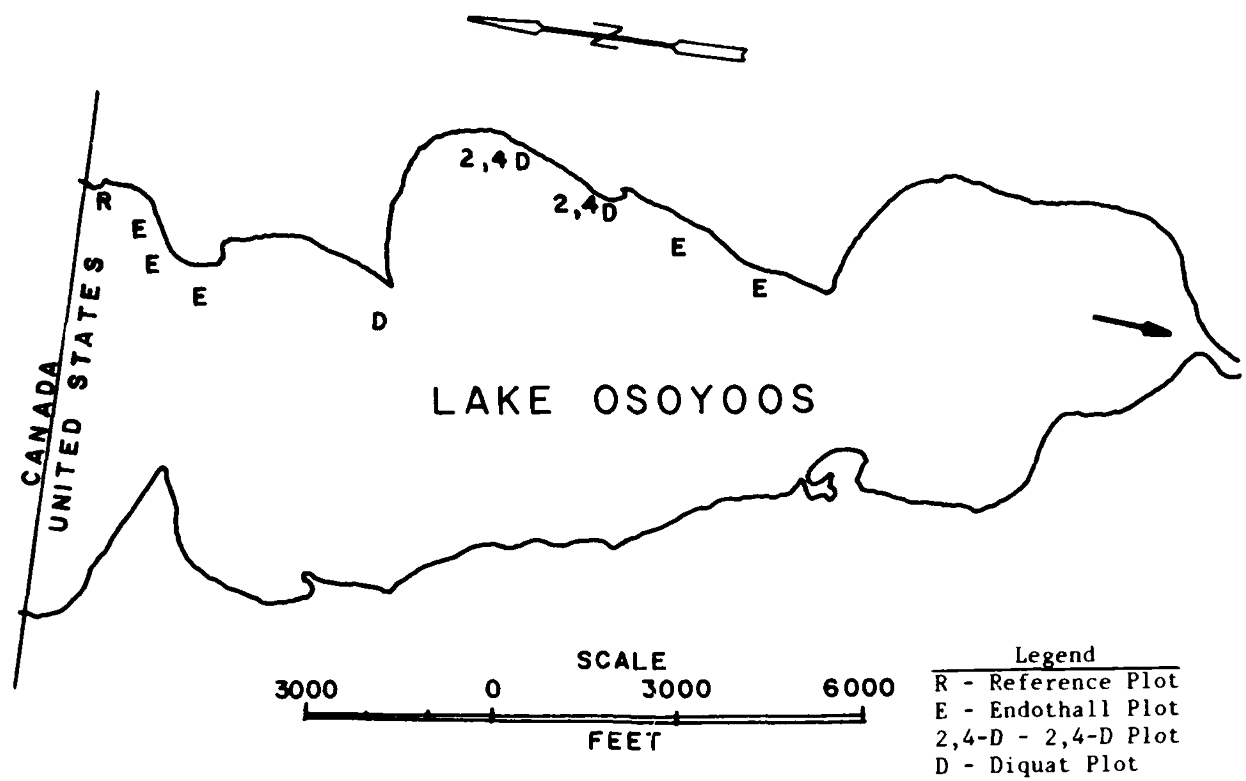

Figure 1. Plot locations, Lake Osoyoos, Washington, 1980

the TI 59 calculator to use AgNaV machine units to compute corner locations and areas of the plots.

Three sampling points for monitoring water quality and herbicide residue changes were established within each treatment plot and parallel to the shoreline. Five points were established for sampling biomass in each treatment plot as well as in the single reference plot. Further, to monitor herbicide drift, two points for sampling residues were established for each treatment plot. One of these was located in a "buffer zone" upstream of each treatment plot. The second was located downstream of each treatment plot. Locations of all of these sampling points were established using the AgNaV position system. Again, this allowed the field team to locate each original sampling point throughout the field study. Table 1 summarizes the sampling scheme.

Data collection techniques

On each sampling date the designated sampling point was located using the AgNaV, marked with buoys, and the appropriate parameters sampled. All treatment or reference plots were sampled identically in each study area. Four of the five endothall plots were initially selected to evaluate controlled-release (CR) herbicides. Endothall was applied to these plots to reduce standing biomass, after which the CR formulations of other herbicides would have been applied. Due to problems with the contractor manufacturing these CR formulations, applications of the CR formulations were not made. However, biomass samples were taken at these plots during the scheduled sampling periods to monitor the effects of the initial endothall application. Collection techniques were as follows:

a. Water quality. Water temperature, pH, dissolved oxygen, and conductivity were measured in situ on each sampling date using a Martek Water Quality Analyzer coupled to a Data Logger, providing a permanent data record on cassette tapes. Measurements were taken at the surface, 1 m below surface, and 0.5 m above the bottom sediment. In addition, water clarity was estimated at each sampling location using a Secchi disk.

b. Herbicide residues. Water samples from the three sampling points within each treatment plot and the single sampling points of the two buffer zones were collected at the surface, 1 m below surface, and 0.5 m above the bottom sediment using a Kemmerer Sampler. Water samples, placed in acid-washed glass bottles for 2,4-D samples and plastic bottles for endothall and diquat, were packed in ice and sent to an analytic laboratory for herbicide residue analysis. Subsequent samples were taken until herbicide analysis revealed less than 0.01 ppm endothall and diquat, and less than 125 ppb 2,4-D, after which analyses were discontinued.

c. Biomass and plant height. The selected biomass samples were collected from each study plot using the WES Biomass Sampler. This sampler is designed to collect aquatic vegetative material

inside a 0.25-sq-m column that extends from the surface of the water to the lake bottom. Plant species were separated from each sample, placed in individual plastic bags, packed in ice, and sent to an analytic laboratory for measurement of wet, dry, and ash weights. Initial biomass samples were taken only in topped-out portions of the milfoil beds contained within plot boundaries. Also, in several plots a fathometer was used before and after treatments to chart plant height and bottom contours. This aided in evaluating herbicidal effects on biomass and height. Successive, parallel fathometer runs were made 6 m apart using a transect subsystem of the AgNaV.

Herbicide application

Only herbicide formulations that are currently registered for aquatic use and are acknowledged as being effective for controlling milfoil at labelled application rates were selected. Diquat and 2,4-D label directions for determining application rates do not consider volume of treatment area. However, to more accurately report herbicide application rates in Lake Osoyoos, a volume was calculated for each treatment plot. Then, the acid equivalent by weight of each herbicide needed to achieve a certain application rate in parts per million was determined. Herbicide formulations and application rates used in this study versus label recommendations, along with relative costs, are presented in Table 2. To help prevent cross-contamination by wind-driven currents between tightly spaced treatment plots, a polymer (Nalquatic) was used in conjunction with liquid herbicides. Used with aquatic herbicides, the label description of Nalquatic's principal use states that it improves sinking, confinement, and contact properties, resulting in more effective aquatic weed control. Herbicides were applied 21-23 July, followed by posttreatment sampling on day 7, 14, 28, and 54.

Results

At the present time, analyses of herbicide residues are not complete. Complete analyses of results for biomass and plant height must await these data. Thus, to preliminarily depict herbicidal effects on specified parameters, data are now presented only in tabular form (Tables 3, 4, and 5). Further, and more synthetic, analyses will be performed when all data are available.

Water quality

The maximum, minimum, and mean values for the water quality parameters are presented in Table 3. Mean values for pH, temperature, and conductivity showed agreement with data for water year 1980 provided by the U. S. Geological Survey (1980). Only dissolved oxygen varied substantially during the study (from 2.50 to 13.41 ppm). Average Secchi disk values in Lake Osoyoos varied from 1.25 m in July and August to 1.50 m in September and October. There were no apparent differences in

water quality between plots during any one sampling period.

Herbicide residues

Maximum and minimum values of herbicide concentration in the water are presented in Table 4. Low herbicide concentrations in the water occurred in all treatment plots from application day through 28 days after treatment. Stratification of herbicide residues in the water column was not evident from preliminary inspection of the data.

Drift of herbicides outside the treatment plots was indicated by defoliated milfoil and low herbicide concentrations in the buffer zones. However, defoliation effects were not as pronounced in the buffer zones, indicating that Nalquatic aided in containment of the liquid herbicides in these treatment plots.

Qualitative herbicidal effects on milfoil

Diquat. Chlorosis of milfoil was evident within 1 week of application, and lysis within 2 weeks. Then, gradual defoliation and subsequent elimination of the topped-out milfoil was observed. High turbidity caused primarily by an extensive blue-green algae bloom impaired visual inspection of the submerged milfoil in all plots after reduction of the topped-out portion of the plant. In addition, foliar marl made qualitative assessment of herbicidal effects on milfoil difficult because the brownish color of the marl on the plants mimicked the chloritic conditions. Approximately 8 weeks after application no milfoil was evident in the upper 1.0 to 1.5 m of the water column. However, growing milfoil that had developed adventitious roots was found at bottom depths, indicating regrowth from either surviving roots, stems, or vegetative fragments that floated into or down within the plot. Twelve weeks after application vertical clumps of milfoil stems that had grown to within 0.5 to 1.0 m of the water surface were observed, indicating continued regrowth from the treatment plot.

Endothall. Although the initial endothall effects on milfoil followed the same general pattern of chlorosis and lysis as with diquat, efficacy (elimination of milfoil) was less pronounced. Four weeks following herbicide application regrowth on the standing stems was observed. In 8 weeks these had grown to within 0.25 m of the surface in water with an average depth of 2 m. An exception was plot 13 where the majority of milfoil stems defoliated and never grew to beyond 1.0 to 1.5 m below the surface.

2,4-D. Observable effects of 2,4-D on milfoil occurred approximately 2 weeks following application. Lysis and defoliation were prevalent after this period, resulting in a rapid decrease of standing crop. No milfoil was observable 4 to 8 weeks after application. However, at the end of the 12-week study period, regrowth resulted in isolated clumps of green milfoil in the shallower areas (1.0 to 1.5 m total depth). Granular 2,4-D appeared to control regrowth more effectively than liquid 2,4-D. Short, vertical stems (0.25 m above the substrate) were observed in the granular plot while longer stems (0.5 to 1.5 m

above the substrate) occurred in the liquid plot.

Most aquatic plant species, other than milfoil, were virtually unaffected by the herbicides. *Potamogeton pectinatus*, *P. richardsonii*, *Egeria densa*, *Nitella* sp., and *Ceratophyllum demersum* continued to flourish in all treatment plots. However, *P. natans* showed partial lysis of its floating leaves in the 2,4-D plots, and *P. crispus* became noticeably less dominant in all treatment plots.

Quantitative herbicidal effects

Herbicide efficacy was quantitated by comparing treatment plot biomass changes to those changes in the single reference plot (Table 5). In the reference plot, milfoil growth appeared vigorous throughout the 4 weeks summarized in Table 5. Average biomass (as ash-free dry weight) of milfoil increased 18.2 percent. By comparison, all treatment plots showed substantial decreases in average biomass. Inspection of decreasing percent reduction of ash-free dry weight of milfoil reveals that the 2,4-D granular treatment showed the most rapid and complete reduction of milfoil biomass, followed by diquat and the 2,4-D liquid, with endothall having substantially less herbicidal effect.

Discussion

Timing of treatment and water quality conditions can effect control. Generally, herbicides are most effective if applied early in the growing season when the plants are beginning to rapidly grow, but before autofragmentation is at a peak. Applications of herbicides in Lake Osoyoos did not occur until mid-July because of State regulations designed to protect salmon runs in June. This delay in application could have reduced the effectiveness of the herbicides because of increased plant density by the time of application.

Product labels for the herbicides suggest applications should be made when water temperature is above 60°F. The average water temperature in Lake Osoyoos was 75°F during application.

High wind speed can result in increased water movement that could disperse herbicides outside the treated area, reducing concentration and contact time. Wind speed averaged 5.0 mph during the 3 days of application. This low wind speed and the use of Nalquatic limited drift of herbicides outside the treated area during this study. There was some evidence of herbicidal activity on milfoil in the buffer zones, but minimal reduction of plant density occurred in those areas.

The overall reduction in plant biomass in each of the types of treatment plots indicated that herbicide concentrations below label recommendation concentrations were effective in causing lysis and defoliation of the milfoil plants. In order of sustained effectiveness, 2,4-D granular was most effective followed by diquat and 2,4-D liquid, which both clearly exceeded endothall. The lower effectiveness of endothall could have been due to reduced concentrations too low to effect desired

control. Most applicators in the Pacific Northwest have used a concentration of 3 ppm of endothall to effectively control milfoil. Since a concentration of slightly less than 1 ppm of endothall had less than the desired degree of effectiveness in Lake Osoyoos, a higher concentration is suggested. In addition, the marl on the foliage may have reduced the contact herbicidal activity of both endothall and diquat.

There are limited data available on the effectiveness of diquat used without other formulations for control of milfoil. However, complete elimination of milfoil was reported by Hestand and Carter (1977) from a controlled laboratory test using 1 ppm diquat and 0.33 ppm Cutrine Plus (copper formulation). A diquat concentration of 1.4 ppm may be effective at keeping milfoil at levels not interfering with navigation without completely eliminating the standing crop.

Both formulations of 2,4-D proved effective in reducing milfoil biomass at the concentrations applied in Lake Osoyoos. Elliston and Steward (1972) report that, in controlled environmental conditions, *M. spicatum* was 100 percent controlled in 8 weeks when subjected to a 1-hr exposure at a concentration of 5 ppm of 2,4-D or to 4 hr at 2.5 ppm. As these investigators decreased concentrations, required exposure time increased and percent control decreased, such that 1 ppm controlled plants if they were exposed for 48 hr. Further, only 0.5 ppm with a 96-hr exposure period was required in these laboratory studies.

Increased exposure time probably improves contact opportunities for a liquid herbicide. Thus, Nalquatic used in conjunction with such herbicides may allow lower application rates without reduced effectiveness and at less cost to the applicator. In addition, when water exchange is high in the area of application, as in Lake Osoyoos, Nalquatic helps prevent herbicide dispersion from the treated area.

The 2,4-D is a systematic herbicide that is absorbed by the plant and translocated by the vascular tissues (Loos 1975). As a result, 2,4-D might be expected to kill root tissues. This was not evident in this Lake Osoyoos study. In contrast, endothall and diquat are contact herbicides affecting contacted foliage and stems. Regrowth can be controlled only if the entire plant is killed by the initial or subsequent retreatment with a herbicide. While 2,4-D, especially in granular form, was most effective in controlling regrowth, none of the tested herbicides totally eliminated regrowth.

The herbicide concentrations used in this study should not be considered minimum concentrations required to effectively control milfoil. However, it is possible to establish a range of herbicide concentration to manage milfoil in similar conditions as in this study. Depending on the initial biomass of the target species population and the use of the water body, low herbicide concentrations may effect control of the target species suitable to the users' interests; for example, a 1-ppm concentration of 2,4-D could reduce plant height to a depth that does not affect navigation. In contrast, higher concentrations of herbicides may be necessary to completely eliminate the standing crop. This research indicates that the use of reduced application rates rather

than the *maximum rates* can provide control adequate for most water bodies and at greatly reduced costs. Selection of the lower yet efficacious herbicide concentrations to effect control suitable to the users' interests is economically and ecologically beneficial.

In order to produce a higher percentage and more sustained reduction in biomass density desirable in a prevention program, herbicide concentrations higher than used in this study or repeated applications may be required. In addition, higher concentrations compensate for underestimates of treatment volume. However, the use of maximum allowable concentrations to control milfoil may result in unnecessary environmental damage and high cost. It is suggested that further research be conducted to determine minimum concentrations of herbicides that yield required reductions of plant biomass at lower cost. The need for better estimations of treatment area volumes, or, even better, volumes as well as better assessments of water users' requirements, is implicit.

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Table 1

Summary of Parameters, Sampling Frequency, and Number of Samples for the Lake Osoyoos Herbicide Evaluation, 1980

Parameters by Category	Number of Samples by Date for Each Plot Type: Treatment Plots (n = 8) Pretreatment	Treatment Plots Posttreatment, days 0	14	28	56	84	Reference Plot (n = 1) Pretreatment	Reference Plot Posttreatment 0	14	28	56	84	Buffer Zone Plots (n = 16) Pretreatment	Buffer Zone Plots Posttreatment, days 0	14	28	56	84	Total No. of Samples
Vegetation																			
Biomass	45	-*	-	45	-	45	5	-	-	5	-	5	-	-	-	-	-	-	150
Plant height	4	-	-	-	-	4	1	-	-	-	-	1	-	-	-	-	-	-	10
Water Quality																			
Water depth	72	72	72	72	72	72	9	9	9	9	9	9	48	48	48	48	48	48	774
Water temperature	72	72	72	72	72	72	9	9	9	9	9	9	48	48	48	48	48	48	774
Dissolved oxygen	72	72	72	72	72	72	9	9	9	9	9	9	48	48	48	48	48	48	774
pH	72	72	72	72	72	72	9	9	9	9	9	9	48	48	48	48	48	48	774
Conductivity	72	72	72	72	72	72	9	9	9	9	9	9	48	48	48	48	48	48	774
Secchi disk depth	72	72	72	72	72	72	9	9	9	9	9	9	48	48	48	48	48	48	774
Herbicide residues in water																			
2,4-D (2 plots)	18	18	18	18	18	-	9	9	9	9	9	-	18	18	18	18	18	18	236
Diquat (1 plot)	9	9	9	9	-	-	9	9	9	9	-	-	6	6	6	6	-	-	96
Endothall (5 plots)	45	45	45	45	-	-	9	9	9	9	-	-	30	30	30	30	-	-	332

* - = not sampled.

Table 2

Cost Comparison for Application Rates Used in Lake Osoyoos Herbicide Evaluation, 1980, Versus Label Recommendations

Herbicide	Price*	Maximum Label Application Rate: Dosage Rate/acre-ft**	Maximum Label Application Rate: ppm/acre-ft†	Maximum Label Application Rate: Price/acre-ft	Lake Osoyoos Applied Rate: Dosage Rate/acre-ft	Lake Osoyoos Applied Rate: ppm/acre-ft	Lake Osoyoos Applied Rate: Price/acre-ft	Cost Savings/acre-ft
Diquat	$55.09/gal	2 gal	1.5	$110.18	1.5 gal	1.12	$82.63	$ 27.55
Endothall	$25.50/gal	2.6 gal	2.86	$ 66.30	0.67 gal	0.735	$17.08	$ 49.22
2,4-D liquid	$14.65/gal	10 gal	14.7	$215.35	1.25 gal	1.84	$18.31	$197.04
2,4-D granular	$49.25/50 lb	200 lb	14.7	$197.00	17.1 lb	1.26	$16.84	$180.16

* Retail price.
** Concentrations based on acid equivalent by weight.
† Parts per million/acre-foot of water.

Table 3

Summary of Water Quality Parameter Data for the FY 80 Herbicide Evaluation in Lake Osoyoos, Washington*

	Water Depth								
	Surface			1 m			Bottom		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum
pH	8.94	8.27	6.84	9.75	8.28	6.76	9.05	8.16	6.87
Temperature, °C	28.78	22.59	16.56	27.76	22.09	16.52	27.24	21.57	17.41
Dissolved oxygen, ppm	12.63	8.32	3.86	13.02	8.78	3.55	13.41	9.01	2.50
Conductivity, μmhos	313	242	200	326	239	201	321	238	183

* Combined from all herbicide treatment plots.

Table 4

Ranges of Herbicide Concentrations in the Water, Lake Osoyoos, Washington, 1980

Herbicide	Bottom Concentrations (ppm)				
	Pretreatment	Day 0	Day 7	Day 14	Day 28
Diquat	0.01-0.02	0.01-0.03	0.01-0.02	0.01-0.02	0.01
Endothall	0.01	0.01-0.33	<0.01	<0.01	<0.01
2,4-D					
Granular	0.125	0.125-0.150	<0.125	<0.125	<0.125
Liquid	0.125	0.125-0.470	<0.125	<0.125	<0.125
Reference	Below the detection limit for all herbicides.				

Table 5

Average Biomass (g/m^2) of Eurasian Watermilfoil, Lake Osoyoos, Washington, 1980*

Plot	Before Treatment			28 Days After Treatment			Percent Reduction		
	Wet Weight	Dry Weight	Ash-Free Dry Weight	Wet Weight	Dry Weight	Ash-Free Dry Weight	Wet Weight	Dry Weight	Ash-Free Dry Weight
Reference	2146.0	313.9	147.9	1798.7	298.9	174.8	16.2	4.8	-18.2
Endothall	882.8	122.4	53.2	488.4	55.2	41.2	44.7	54.9	22.6
Diquat	2325.6	333.2	122.8	214.8	24.0	6.4	90.8	92.8	94.7
2,4-D									
Liquid	363.1	139.0	49.1	445.6	85.0	14.1	69.0	84.7	71.3
Granular	420.0	64.7	15.9	0.33	**	**	99.9	**	**

* Average values based on five samples/sampling period/plot.
** weight below the detection limit.

LARGE-SCALE OPERATIONS MANAGEMENT TEST

Efficacy of Mechanical Harvesting and Its Influence Upon Carbohydrate Accumulation in Eurasian Watermilfoil

by

Michael A. Perkins* and Mark D. Sytsma*

Introduction

Background

Mechanical harvesting as an option for aquatic plant management is widely practiced throughout the United States and Canada. In instances where chemical control techniques are restricted, harvesting represents one alternative for the management of nuisance growth of submersed aquatic plants.

While the immediate benefits to be derived from a harvesting operation are clear, the duration of that benefit within the same growing season and the extent of carry-over to subsequent seasons are subject to question. It is perhaps an unfortunate reality that plants, once cut, tend to regrow. The rate of this regrowth can be rapid and sufficient to offset initial plant biomass reductions in a relatively short period of time.

A review of the literature indicates the relative paucity of information regarding the effectiveness of mechanical harvesting, particularly in respect to long-term benefits (i.e., carry-over to subsequent seasons of growth). Those studies that have been reported (Mossier 1968; Nichols and Cottom 1972; Rawls 1975; Wile et al. 1977; Kimbel and Carpenter 1979; Perkins, Boston, and Curren 1979; Perkins 1980) suggest that enhanced effectiveness is derived from multiple cuttings. The number of studies, however, are few and the results somewhat variable.

Based on observed regrowth rates, it is clear that, for water bodies impacted by growth of submersed plants such as Eurasian watermilfoil, multiple cuttings during the high use summer growing season would be required to optimize recreational use of that water. The application of mechanical harvesting in response to the desires of user groups would appear to be typical of most operations. While such an approach is necessary, it does relegate the harvesting alternative to one of immediate nuisance control which may detract from a longer term perspective.

Clearly, aquatic plants respond to temporal variations in their

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environment in a set and relatively predictable fashion. Such would appear to be the case with respect to carbon gain and allocation by Eurasian watermilfoil. The accumulation of nonstructural carbohydrates in shoot and root tissues during the summer and fall periods was apparently a response to the onset of stressful winter conditions in Lake Mendota (Titus 1977; Titus and Adams 1979). Presumably, utilization of these stored reserves accompanies the spring growth flush and may enhance the development of an early season biomass. Kimbel and Carpenter (1979) report similar observations for Eurasian watermilfoil in Lake Wingra.

If harvesting could be coordinated with respect to temporal variations in ecophysiological activities of the target plant, a management alternative with a longer term benefit may derive. Such an approach with regard to accumulation and translocation of nonstructural carbohydrates has been suggested by Kimbel and Carpenter (1979). The objective would be to implement the harvest at a period of time so as to reduce the accumulation of carbohydrate reserves in roots and overwintering shoots and hence impede the growth flush the following spring.

The specific objectives of the work reported herein were:

a. To assess long-term biomass reductions and changes in community composition attributable to 1979 harvest operations.

b. To evaluate the short-term (within same growing season) effectiveness of a multiple cut strategy in 1980 based upon biomass reduction and regrowth characteristics.

c. To evaluate the seasonal variation in carbohydrate translocation and accumulation by Eurasian watermilfoil and assess its relationship to harvesting.

Methods and Materials

Harvesting operations were conducted on a 0.3-ha (0.76-acre) experimental plot of Eurasian watermilfoil within Union Bay of Lake Washington over the past three growing seasons (1978 to 1980). The results of the 1980 operations are the subject of this report. (The results of the first 2 years have been reported previously (Perkins, Boston, and Curren 1979; Perkins 1980).) Of significance to the present study were the 1979 operations in which two cuts were conducted, one in July and one in October. The scheduling of the 1979 operations was directed largely by a desire to evaluate the carry-over benefits from a two-cut program. The inclusion of the October harvest was for the purpose of plant biomass removal prior to maximum fragmentation and to attempt to block carbohydrate translocation and accumulati n in roots and overwintering shoots.

The study was conducted within Union Bay at the outlet of Lake Washington. The same plot locations that were used over the two previous growing seasons were again used. The 0.3-ha treatment plot that

had been harvested twice in 1979 was harvested three times during the 1980 growing season. The initial harvest was conducted by the Municipality of Metropolitan Seattle (METRO) on 28 July and utilized a Mudcat (Altosar) harvester with a 7-ft cutting width and a 5-ft cutting depth. The second cut was conducted on 22-23 August by Marmot, a local firm using an Aquamarine CHUB on lease from the Washington Environmental Council. The third cut was conducted on 22 October, again by Marmot using the Aquamarine CHUB.

Water depth throughout the study area ranged from 1 to 2 m. The area contained a uniformly distributed mixed plant community largely dominated by Eurasian watermilfoil. The harvest plot was cut along its northeast corner by a large sandbar that supported a very sparse plant growth. This sandbar was eliminated from consideration during sampling for biomass estimation within the harvest plot.

Sampling for biomass estimation was accomplished by SCUBA diver utilizing a 0.25-m^2 cylindrical sampler. On each sampling event five samples were taken from both the treatment and control plots (control located adjacent to the treatment plot). Collected plant materials were returned to the laboratory, washed free of periphyton and debris, sorted by species, and placed into a drying box at 60°C for 48 hr prior to weighing. Due to uncertainties in regard to the extent of root removal, values are reported herein as shoot biomass only. Samples were taken immediately prior to the initial cut and then again at approximately 1-week and 1-month postcut intervals. For sequential cutting on the plot, the 1-month postcut condition served as both the regrowth estimator and sequential precut estimator.

Sampling for carbohydrate estimation consisted of random selection of five whole plants (root crowns plus attached shoots) by diver from both harvest and control plots. Samples were taken on eight dates over the period 13 July to 3 November.

Samples for carbohydrate extraction were returned to the laboratory, washed free of periphyton and debris, and root/shoot tissues from individual plants separated. Four to five grams of root and shoot material (5-cm apical cuttings) was transferred to labeled test tubes and then freeze dried for 24 hr prior to extraction. For all samples, initial preparation occurred within 2 hr of collection. Following drying, the individual samples were ground to a fine powder and 40- to 50-mg subsamples were taken for extraction.

A two-step extraction procedure was used in an attempt to isolate the contribution of free sugars (primarily sucrose) and storage sugars (fructosans and starch) to the nonstructural carbohydrate pool. The initial extraction was in 80 percent ethanol at 50°C (3 · 15 min) with pooling of the three extracts for determination of sugar content. Following ethanol extraction, the residue was then extracted with boiling water (3 × 15 min) again with pooling of the extracts for sugar determination. The extraction scheme was a mofification of those described by Pucher, Levenworth, and Vickery (1948); McCready et al. (1950); Smith, Paulsen, and Raguse (1964); and Koziol and Jordan (1978). The sugar

content of each fraction was estimated by the phenol-sulfuric acid colorimetric technique of Dubois et al. (1956). For each set of samples run, a standard curve was derived from a least squares fit of dextrose standards covering the range of determination.

The extraction scheme utilized for nonstructural carbohydrate removal differed from the extractions used by other workers in that a step for the hydrolytic cleavage of starches was eliminated. This omission reduced the degree of comparability between the nonstructural carbohydrate values and those reported, most significantly, by Titus (1977) and Kimbel and Carpenter (1979), who utilized the takadiastase enzyme method of Weinmann.

The boiling water extraction was tested against both dilute perchloric and sulfuric acid extraction on the ethanol insoluble residue; 0.2 N H_2SO_4 was used due to its reported comparability to the enzyme extraction (Smith, Paulsen, and Raguse 1964) and various concentrations of perchloric acid because it has been widely used for starch extraction. It was found that both acids continued to remove variable but significant quantities of sugar from the ethanol insoluble residue after as many as eight sequential extraction steps. The water extractable fraction rapidly decreased to base level after three or four extraction steps (Figure 1). It was concluded that both acids were removing structural carbohydrates (e.g., hemicellulose) which would interfere with the assessment. We settled on the boiling water extraction largely because it yielded a consistent result even though we recognized that starch, if present, would be underestimated.

Results and Discussion

Variation in biomass

The results of the 1980 biomass sampling are presented in Table 1 which shows the species composition and the mean dry weight per species per sample. The data are further summarized in Figure 2 which shows the temporal variation in mean dry weight biomass.

Relative to the objective of determining harvesting efficacy, biomass reduction as a result of the harvest was estimated as the difference between the precut biomass and the 1-week postcut biomass. Regrowth was estimated as the mean accrual of dry weight biomass between the 1-week and 1-month postcut conditions. Overall effectiveness was determined as the percent reduction in dry weight biomass relative to the untreated control plot.

The initial question being addressed related to the long-term (between growing seasons) effectiveness of the two harvest program in 1979. The null hypothesis was one of equality of mean biomass between harvest and control plots in 1980 prior to any further manipulation of the harvest plot.

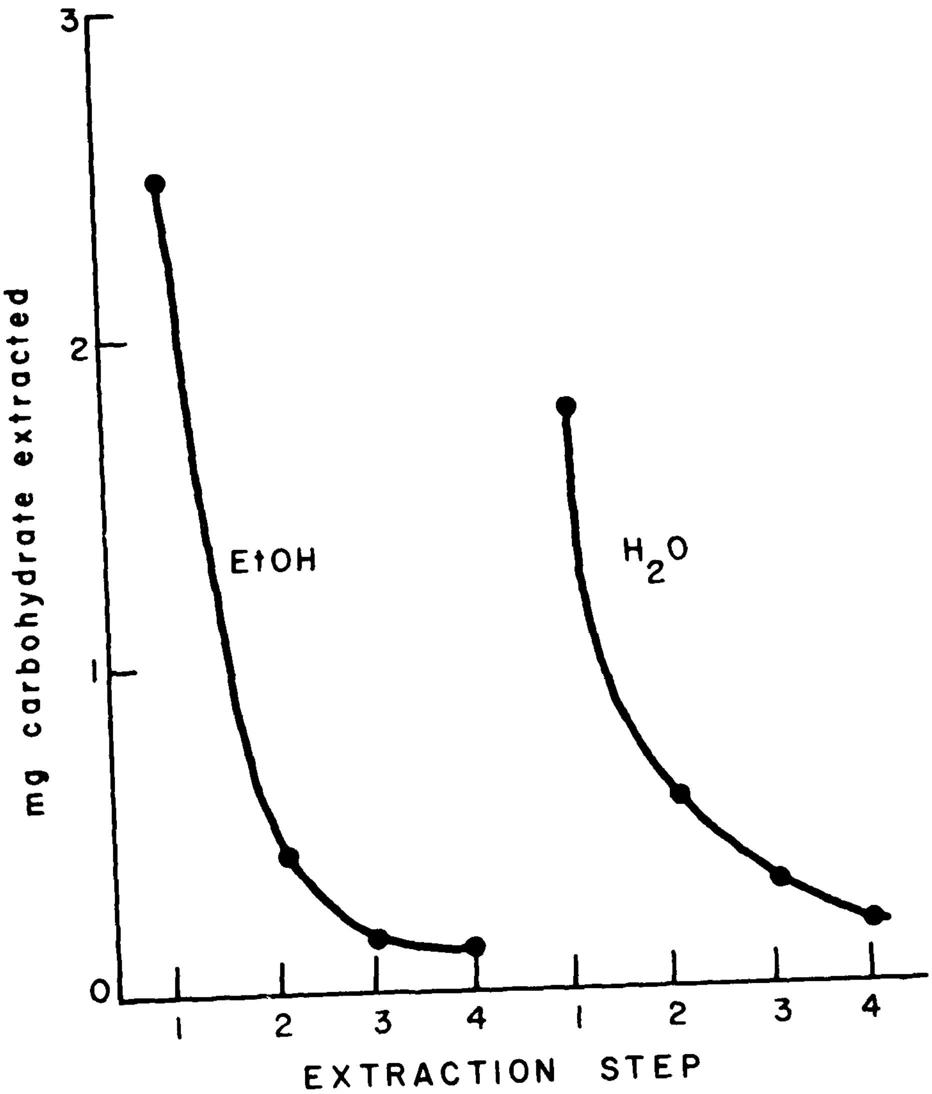

Figure 1. Result of a typical sequential carbohydrate extraction with 80 percent ethanol followed by boiling water extraction of the ethanol insoluble residue

Visual observation of the plots in July 1980 indicated very little difference in general appearance between control and harvest plots. Eurasian watermilfoil was the dominant plant in each plot although both contained a mixture of aquatic plants. The most striking feature of the plots was that they appeared to contain substantially less plant material than was present in July 1979.

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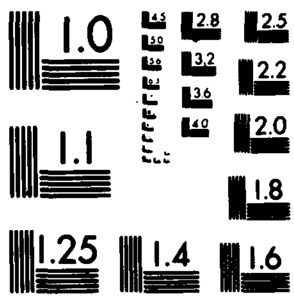

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

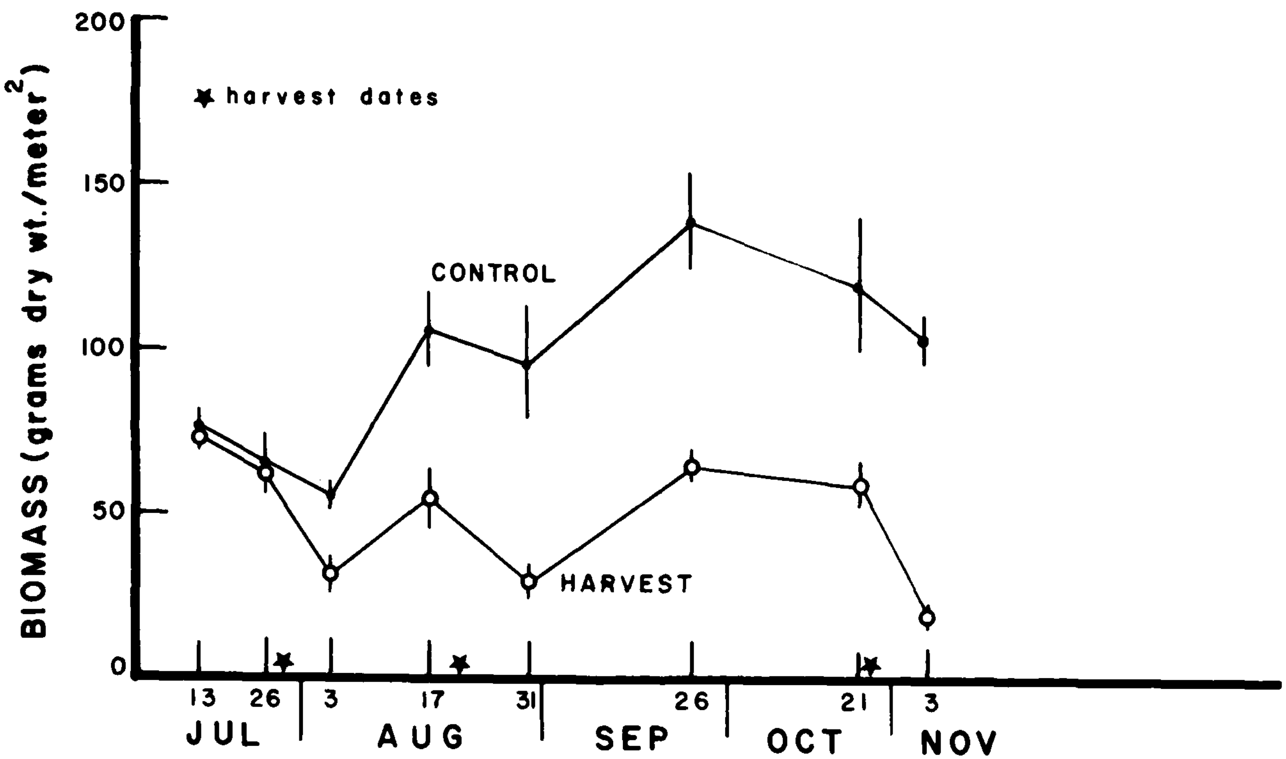

Figure 2. Variation in dry weight biomass within the control (●) and harvest (O) plots during the 1980 growing season. Harvesting dates were 28 July, 22, 23 August, and 22 October

Initial biomass sampling was conducted on 13 and 26 July. The results of these samplings indicated no significant differences between dates within plots; hence, the data were pooled to give 10 replicates in each plot for the between plot comparison. A logarithmic transformation of the data was used to satisfy the assumption of equality of variance, and a t-test for equality of means was used. The test indicated no significant difference in mean biomass between the plots ($p = 0.05$). The overall means and 95 percent confidence intervals were 68.5 ± 6.59 and 69.5 ± 3.48 g dry weight/m^2 for the harvest and control plants, respectively.

The biomass estimates confirmed the observation of a much reduced plant mass in July 1980, relative to July 1979. Dry weight biomass in July 1979 averaged 197 ± 54 g/m^2 and would suggest the substantial year-to-year variation that can occur. It is possible that the magnitude of the overall biomass reduction in 1980 may have masked any effect due to the 1979 harvest.

The initial 1980 harvest occurred on 28 July and resulted in a biomass reduction from 62.8 ± 17.4 to 30.4 ± 6.2 g dry weight/m^2 (51.6 percent removal). The plots were resampled on 17 August, and over the intervening 14-day period dry weight biomass had increased to 53.2 ± 9.6 g/m^2 for a regrowth rate of 1.63 g dry weight/m^2/day. Relative to the control, however, biomass was reduced by approximately 49 percent.

The second harvest occurred on 22 and 23 August and resulted in a biomass reduction of 25.6 g dry weight/m^2 (48.1 percent removal). The 1-month postcut sampling occurred on 26 September, and over the intervening 25-day period dry weight biomass had increased to 61.6 ± 4.9 g/m^2 for a regrowth rate of 1.36 g dry weight/m^2/day. Overall, for the 26 September sampling date, the result of the second harvest was a 55.2 percent reduction relative to the control biomass. An additional biomass sampling occurred on 21 October (3rd harvest precut) and indicated a slight decrease in average biomass within both harvest and control plots. The percent biomass reduction within the harvest plot relative to the control plot was approximately 50 percent.

The third harvest occurred on 22 October and resulted in a reduction of 40 g dry weight/m^2 (69.9 percent removal). Overall, the effect of the three harvests in 1980 was to reduce the mean dry weight biomass within the harvest plot in November by approximately 83 percent. For all dates after 3 August, mean dry weight biomass within the harvest plot was significantly less than that occurring within the control.

Projected biomass values for the harvest plot based upon observed regrowth rates within that plot would yield values of 76 g/m^2 on 31 August and 111 g/m^2 on 26 September. These values would not be significantly different from the control biomass and would suggest the relative ineffectiveness of a single harvest in late July.

Carbohydrate accumulation

The results of the carbohydrate extractions on root and shoot tissues collected from the harvest and control plots are presented in

Table 2. Values are expressed as milligrams sugar/gram dry weight. Nonstructural carbohydrates are the sum of the ethanol and water soluble fractions.

The temporal variation for the individual root/shoot fractions expressed as a percent of dry weight is shown in Figure 3. Over the period of investigation, the shoot nonstructural carbohydrates averaged 7.9 percent in the control plants and 7.3 percent in the harvest plants with a combined range of 5.3 to 10.3 percent dry weight. The ethanol soluble fraction contained the major component of the shoot nonstructural carbohydrates averaging 63 percent in the control plants and 67 percent in the harvest plants. The root nonstructural carbohydrates averaged 12.1 percent in the control plants and 10.3 percent in the harvest plants over a combined range of 3.8 to 17.5 percent dry weight. The ethanol soluble fraction again constituted the major component of the nonstructural carbohydrate pool, averaging 76 percent in the control plants and 74 percent in the harvest plants.

The ranges for nonstructural carbohydrates reported here are quite similar to those reported by Titus (1977) and Titus and Adams (1979) for *M. spicatum* in the Madison Lakes and would suggest a degree of comparability even though the extraction procedures differed. The dominance of the ethanol soluble fraction would suggest that free sugars (e.g., sucrose) would be the major storage products and this might account for the absence of "conspicuous storage organs" in *M. spicatum* (Titus and Adams 1979). Christy and Swanson (1976) reported on the importance of a sucrose transport pool in regulating translocation in young sugar beets (*Beta vulgaris*) and our findings on the dominance of a free sugar pool in milfoil may not be unexpected.

The temporal variations in root/shoot nonstructural carbohydrates for control and harvest plants are summarized in Figure 4. The values are plotted as mean milligrams of sugar per gram dry weight with a one standard error bar about the mean.

The objective of the carbohydrate sampling was centered on three major hypotheses: first, that *M. spicatum* translocates and stores nonstructural carbohydrates in root tissues during the period when photosynthetic production exceeds the demands for plant maintenance and growth. Secondly, we hypothesized that the removal of photosynthetic plant tissues through harvesting would inhibit this process of carbohydrate accumulation; and, thirdly, reduction in the root accumulation of reserve carbohydrates would translate to a reduced plant biomass during the subsequent spring growth flush. The field sampling program was designed to address and test these hypotheses, the criterion variables being within-plot shoot-to-root concentrations and between-plot shoot-to-shoot and root-to-root concentrations. A one-way ANOVA and least significant difference procedure was used to test these a priori comparisons.

Variation in nonstructural carbohydrates within root and shoot tissues of plants collected from the control plot indicated a very definite seasonal pattern with increased root accumulation in August to a

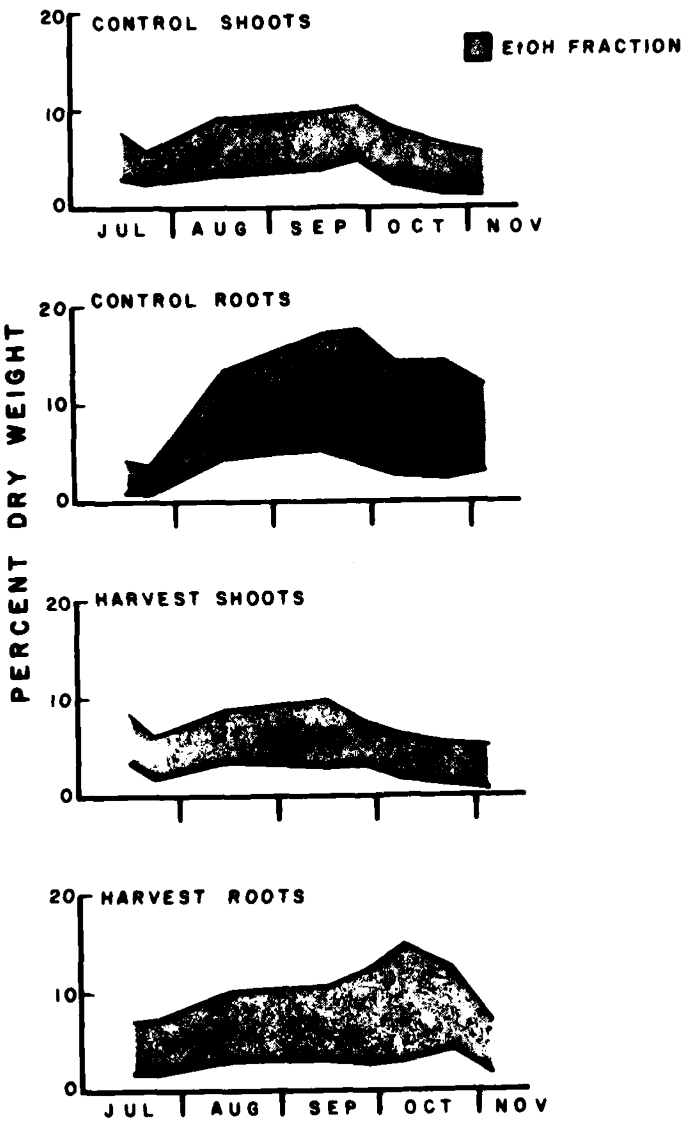

Figure 3. Variation in ethanol soluble, water soluble, and total extractable carbohydrates within root and shoot tissues of Eurasian watermilfoil. Values are expressed as percent dry weight. Shaded areas represent the ethanol soluble fraction

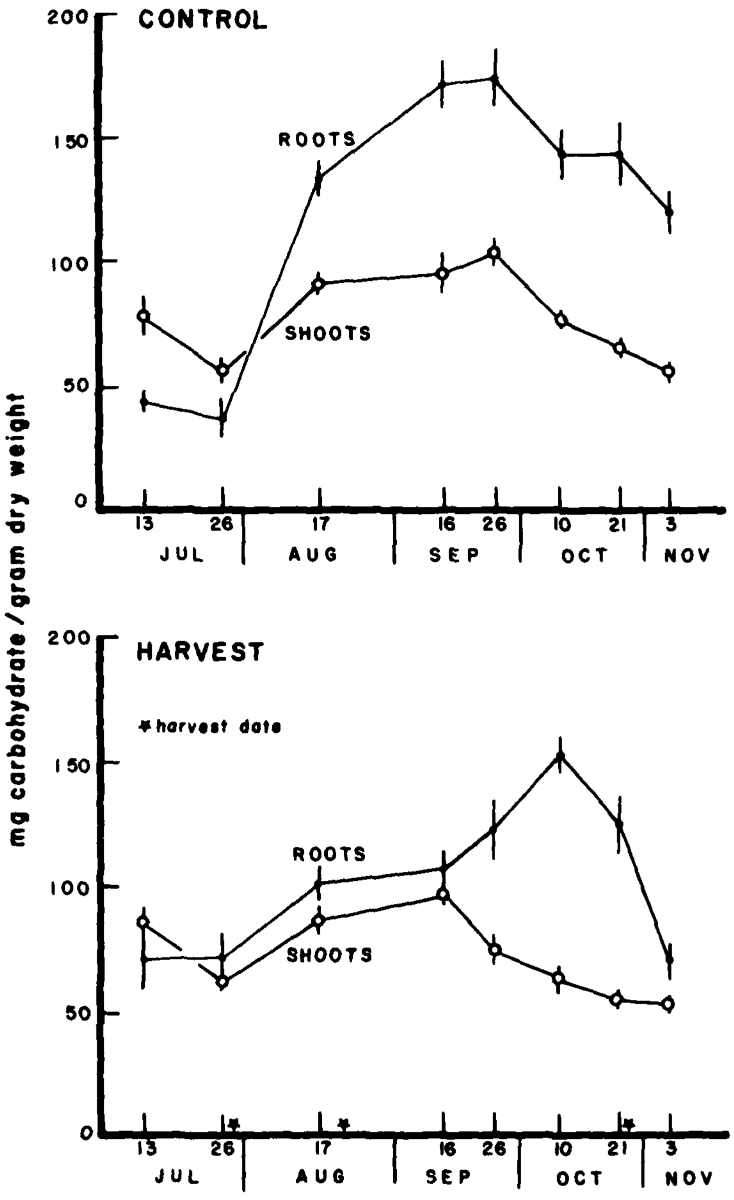

Figure 4. Temporal variation in nonstructural carbohydrates in root and shoot tissues of Eurasian watermilfoil collected from control and harvest plots within Union Bay

peak value of 175.2 ± 11.14 mg sugar/g dry weight in September followed by a decline to approximately 121 mg/g dry weight in November. In the initial July sample, shoot concentrations were significantly greater than root concentrations, but 2 weeks later there was no significant difference between shoots and roots. Cross-over occurred in August, and for all sampling dates from 17 August on, root concentrations were significantly greater than shoot concentrations.

Plants collected from the harvest plot showed no significant difference between root and shoot concentrations until the 26 September sampling date (approximately 1 month after the second harvest) at which time root concentrations increased dramatically to values significantly greater than those occurring in shoot tissues. Root concentrations declined through October and showed a drastic reduction in November following the third harvest. Shoot and root concentrations were not significantly different on the 3 November sampling date.

The between-plots comparison for shoot concentration of nonstructural carbohydrates indicated no significant differences between harvest and control plants with the exception of the 26 September and 10 October sampling dates, at which time the control plants were significantly greater than the harvest plants. This was the same period of time for which carbohydrate concentrations in the harvest roots were increasing and may reflect a rapid translocation from shoots to roots.

The between-plots comparison of root carbohydrates indicated that the control plant roots had significantly greater concentrations than the harvest plant roots until the October sampling dates, at which time the two were not significantly different. The 3 November sampling indicated that the control plant roots were again significantly higher in nonstructural carbohydrate content, the late October harvest evidently resulting in a rapid loss of nonstructural carbohydrates from the roots of the cut plants.

The results of the carbohydrate analysis would lead to acceptance of the first two hypotheses. Clearly, Eurasian watermilfoil did translocate and store nonstructural carbohydrates within root tissues during the summer and fall periods in Union Bay. It was also evident that harvesting inhibited this process and resulted in significantly reduced nonstructural carbohydrate concentrations in late fall root tissues. The third hypothesis, that of translocation to a reduced spring growth flush, must await further analysis.

Conclusions

Several trends in regard to harvesting efficacy and carbohydrate accumulation by Eurasian watermilfoil were evident in the data collected. Clearly, a single cut program would be relatively ineffective in providing even short-term benefits to a harvest program. A minimum of two cuts during the high use summer season would be necessary to provide

relatively modest short-term benefits (55 percent reduction in biomass) and this may have only limited carry-over to the following year if the harvests are timed so as to leave adequate time for the restoration of an overwintering biomass. The failure of the 1979 harvests to reduce biomass in 1980 may be attributable to the overall reduction in milfoil growth throughout Union Bay in 1980 and any influence upon spring growth flush would have been missed by the late starting date (sampling in 1980 did not begin until July).

Harvesting had a very definite impact upon carbohydrate accumulation by Eurasian watermilfoil and, if we assume that reserve carbohydrates are significant in terms of overwinter survival and subsequent spring growth flush, proper timing of the harvest may lead to substantial long-term reductions in biomass. The data indicated that harvesting resulted in significant reductions in carbohydrate accumulation but the effect was transitory in the sense that root concentrations in harvested plants were rapidly restored to levels not significantly different from control plants. Without the late October harvest there would have been no influence upon root concentrations. The phenomenon of carbohydrate replenishment following cutting has also been described for orchard grass (*Dactylis glomerata*) by Sprague and Sullivan (1950) and for Johnson grass (*Sorghum halepense*) by McWhorter (1974).

Tentatively, a multiple cut harvesting program would seem necessary in order to provide short-term reductions in aquatic plant biomass with a mandatory late season cutting if longer term benefits are desired. It seems possible that substantial reductions in biomass during the 1981 growing season may result from the 1980 harvests; this will be evaluated this coming spring.

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of the Washington Environmental Council and the employees of Marmot for their conduct of two of the harvesting operations. Finally, we are indebted to the Municipality of Metropolitan Seattle (METRO), without whose cooperation and assistance the 1980 harvests on our treatment plots would not have been possible.

Table 1. Summary of dry weight biomass within harvest and control samples from Union Bay Study site. Harvesting occurred on 28 July, 22 August, and 22 October 1980.

	grams dry weight/sample (± 1 SE , n=5)							
	7/13	7/26	8/3	8/17	8/31	9/26	10/21	11/3
CONTROL PLOT								
Myriophyllum spicatum	18.6±1.83	14.3±2.42	13.4±1.58	26.1±3.05	22.4±4.44	34.0±3.63	28.8±5.21	25.8±2.18
Potamogeton richardsonii	< 0.1	1.0±0.93	0.1±0.12	< 0.1	1.4±0.85	0.3±0.22	---	---
P. crispus	---	---	---	---	---	---	---	---
P. berchtoldii	< 0.1	0.4±0.36	< 0.1	< 0.1	---	---	---	---
P. pusillus	---	---	---	< 0.1	< 0.1	< 0.1	---	---
Ceratophyllum demersum	---	---	---	---	---	---	---	---
Najas flexilus	---	< 0.1	---	< 0.1	< 0.1	< 0.1	---	---
N. sp.	---	---	---	< 0.1	<---	< 0.1	---	---
Elodea canadensis	---	---	---	< 0.1	< 0.1	---	---	---
Chara sp.	0.2±0.11	< 0.1	< 0.1	0.1±0.04	< 0.1	< 0.1	---	---
TOTAL	18.9±1.89	15.8±2.47	13.6±1.6	26.3±3.09	23.9±4.57	34.4±3.50	38.8±5.21	25.8±2.20
HARVEST PLOT								
Myriophyllum spicatum	16.7±4.72	15.6±4.36	7.5±1.53	12.8±2.36	6.3±1.21	14.2±1.21	14.0±2.10	4.1±0.93
Potamogeton richardsonii	1.5±1.28	---	< 0.1	0.3±0.27	< 0.1	1.02±0.66	0.3±0.28	0.1±0.08
P. crispus	---	< 0.1	---	---	---	---	---	---
P. berchtoldii	0.2±0.07	< 0.1	< 0.1	< 0.1	---	---	---	---
P. pusillus	---	---	---	< 0.1	< 0.1	< 0.1	---	---
Ceratophyllum demersum	< 0.1	< 0.1	---	---	---	---	< 0.1	---
Najas flexilus	---	< 0.1	< 0.1	< 0.1	0.3±0.21	0.1±0.08	< 0.1	---
N. sp.	---	---	---	< 0.1	< 0.1	< 0.1	<---	---
Elodea canadensis	---	---	---	< 0.1	< 0.1	0.1±0.04	< 0.1	< 0.1
Chara sp.	0.2±0.14	< 0.1	---	< 0.1	< 0.1	< 0.1	< 0.1	---
TOTAL	18.5±4.40	15.7±4.35	7.6±1.56	13.3±2.41	6.9±1.42	15.4±1.23	14.3±1.84	4.3±0.88

Table 2. Extractable carbohydrate content of Eurasian watermilfoil root and shoot tissues collected from harvest and control plots of Union Bay, 1980 (EtOH = ethanol extractable fraction; HOH = boiling water extractable fraction; Σ ext = total extractable; all values are means ± 1 SE for n = 5 replicates).

	mg sugar/gram dry weight							
CONTROL PLANTS	7/13	7/26	8/17	9/16	9/26	10/10	10/21	11/3
SHOOT								
EtOH	48.4±3.16	32.6±2.17	62.6±5.31	56.2±4.08	54.5±2.93	52.3±1.75	50.5±2.83	46.0±1.66
HOH	31.0±6.45	24.5±5.55	28.7±3.69	40.2±8.26	49.0±5.63	25.1±2.28	16.0±4.25	12.4±0.84
Σ ext	79.4±8.14	57.1±6.19	91.3±6.38	96.4±8.00	103.5±5.93	77.3±1.84	66.5±5.16	58.4±2.35
ROOT								
EtOH	32.7±3.18	29.4±6.33	91.0±4.84	117.9±5.10	137.4±9.06	115.7±8.47	119.9±7.46	89.6±5.59
HOH	10.6±0.96	9.3±1.55	43.5±5.42	53.6±5.42	37.8±3.42	27.6±3.95	24.1±6.04	31.2±3.81
Σ ext	43.3±3.95	38.6±7.24	134.5±8.35	171.5±9.29	175.2±11.14	143.3±9.80	144.0±13.16	120.8±8.53
HARVEST PLANTS								
SHOOT								
EtOH	50.2±3.08	42.1±4.83	52.1±4.67	68.6±3.86	44.2±1.40	44.1±3.93	44.0±1.32	43.5±3.17
HOH	36.5±5.04	19.1±3.61	35.9±4.58	30.1±0.61	32.3±2.50	19.9±1.01	11.6±0.75	9.6±0.98
Σ ext	86.7±5.95	61.2±2.40	88.0±6.35	98.7±4.14	76.5±3.22	64.0±4.83	55.6±1.56	53.0±3.35
ROOT								
EtOH	54.3±11.64	57.2±7.19	70.2±6.00	77.0±5.24	96.5±11.53	119.4±6.12	82.6±4.32	54.0±5.01
HOH	16.6±3.76	15.8±2.72	31.4±0.52	31.5±1.75	27.7±1.96	31.5±2.49	42.8±10.01	17.6±3.35
Σ ext	70.8±13.55	73.0±9.71	101.6±5.71	108.5±6.38	124.2±13.11	150.9±7.27	125.9±12.87	71.6±7.48

LARGE-SCALE OPERATIONS MANAGEMENT TEST

Use of Biological Agents for Control of Waterhyacinth in the New Orleans District

by

Russell F. Theriot*

Introduction

This session involves work being conducted in Louisiana for, and funded by, the U. S. Army Engineer District, New Orleans, under the Aquatic Plant Research Program (APCRP) at the WES. The research is designated as a Large-Scale Operations Management Test (LSOMT), and is being conducted on waterhyacinth (*Eichhornia crassipes* (Mart.) Solms), utilizing insects and a plant pathogen. I will present a general overview and status of the project. Dr. A. F. Cofrancesco, Jr., and Mr. Edwin A. Theriot will then discuss in greater detail two of the major field efforts initiated this past year.

LSOMT

Background studies

Several background studies were necessary prior to the initiation of the LSOMT. This background research can be divided into four reasonably distinct efforts, as follows:

a. *Cercospora rodmanii* Conway research performed by the University of Florida, and subsequent *Cercospora* formulation research being conducted by Abbott Laboratories, Chicago, Illinois.

b. *Neochetina eichhorniae* Warner and *N. bruchi* Hustache research performed by the U. S. Department of Agriculture, Science and Education Administration (USDA-SEA) in Florida, and the subsequent distribution of these insects in Louisiana by the Louisiana Department of Wildlife and Fisheries.

c. The Lake Concordia study conducted by the WES to evaluate candidate organisms on a small scale.

d. *Sameodes albiguttalis* Warren research performed by USDA-SEA in Florida to develop methods for establishment of the insect in the field.

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Results of these background studies were used as a basis for selecting the species to be included in the LSOMT, except in the case of *Arzama densa* Walker. This species was included because it is very destructive on waterhyacinth and could contribute significantly to the control of the target plant if produced and released in sufficient numbers.

<u>Purpose and objectives</u>

The purpose of this study is to develop and demonstrate an operational capability for the use of selected combinations of insects and pathogens for control of waterhyacinth. The general objectives of this study are:

<u>a</u>. To determine the necessary and sufficient means for establishment of effective field populations of test organisms.

<u>b</u>. To demonstrate the effectiveness of test organisms when used at an operational scale.

<u>c</u>. To determine environmental limitations on the test organisms.

Test organisms being evaluated in the LSOMT include: *Cercospora rodmanii* Conway, a plant pathogen; *Neochetina eichhorniae* Warner and *N. bruchi* Hustache, weevils; and *Sameodes albiguttalis* Warren and *Arzma densa* Walker, moths.

<u>Research efforts</u>

To accomplish the objectives of the test, the LSOMT was divided into four separate research efforts, as discussed below.

<u>Pilot field study.</u> This aspect of the LSOMT was designed to determine whether or not spot applications of *C. rodmanii* would be sufficient to effect widespread infection and control of waterhyacinth.

<u>*Cercospora* formulation studies.</u> To establish a range of treatment rates that provide significant infection of waterhyacinth by *C. rodmanii*, a small-scale rate study was conducted at the WES.

<u>Supportive studies.</u> Field evaluation was conducted of application equipment to determine if equipment already available and presently in use by the New Orleans District could be used to apply *Cercospora* and result in infection of waterhyacinth. Mass-rearing techniques for *A. densa* are being developed by research conducted by the USDA-SEA research facility at Stoneville, Mississippi.

<u>Large-scale field application tests.</u> The large-scale field application tests form the most important part of the LSOMT and involve several large-scale applications of the test organisms to simulate operational level conditions. These tests are designed to provide the necessary data to develop the framework for an operational system for biocontrol of waterhyacinth in the New Orleans District. The resulting framework should also be applicable to other Districts and areas where waterhyacinth is a problem.

Test scenarios

Several test scenarios will be evaluated to obtain these data, and include:

a. *Sameodes albiguttalis* applied alone.

b. *Sameodes albiguttalis* and *C. rodmanii* applied to the same site.

c. *Cercospora rodmanii* applied in the spring.

d. *Cercospora rodmanii* applied in the fall.

e. *Arzama densa* applied alone.

f. A combination of all organisms applied to a site.

Since *Neochetina eichhorniae* and *N. bruchi* have been successfully established and are now widespread in Louisiana due to the efforts of the Louisiana Department of Wildlife and Fisheries, they must be considered as a part of each of the above scenarios and should contribute to the overall impact on waterhyacinth.

Data collection

The general types of data being collected in these studies include abundance, biomass, and reproduction of waterhyacinth; population density; spatial distribution; impact of the test organisms and other naturally occurring arthopods and pathogens on waterhyacinth, and data pertaining to general system qualities, water quality, and meteorology. More detailed presentations of data collection and analysis and other aspects of the LSOMT are presented in a published test plan, WES Instruction Report A-79-1.* If you are on the mailing list for reports of the APCRP, you will receive all of the reports that have or will result from this research. If you are not on this mailing list but wish to obtain copies of these reports, contact Mr. W. N. Rushing of the APCRP, who will add your name to the mailing list.

Summary

In summarizing the progress of the LSOMT since January 1980, the following has been accomplished:

a. The pilot field study has been completed and the report is presently being prepared.

b. An Experimental Use Permit and research label has been received from the Environmental Protection Agency for evaluating *C. rodmanii* in large-scale field tests.

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* Sanders, D. R. et al. 1979. "Test Plan for the Large-Scale Operations Management Test of Insects and Pathogens for Control of Waterhyacinth in Louisiana," Instruction Report A-79-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

c. A successful rearing technique was developed by USDA at Stoneville, Mississippi, for *A. densa*.

d. Several systems for application of *C. rodmanii* have been evaluated, including garden sprayers, roadside application equipment, airboat-mounted sprayers, and aerial application equipment. Both centrifugal and impeller-driven pumps were included. It was shown that infection of *C. rodmanii* can be achieved with any of these systems.

e. *Sameodes albiguttalis* has been established on waterhyacinth in Louisiana and is dispersing.

f. Three of the large-scale tests have been initiated, including applications of *S. albiguttalis*, *A. densa*, and *C. rodmanii*, and data are presently being collected at these sites.

LARGE-SCALE OPERATIONS MANAGEMENT TEST

Mass Release of *Arzama densa*

by

A. F. Cofrancesco*

Introduction

Arzama densa Wlk. is a native North American noctuid moth. Orignally, the larvae fed on pickerelweed (*Pontederia cordata* L.), but now they also utilize waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) as a food source. The larvae tunnel into the petioles and crown of the waterhyacinth plant and produce extensive feeding damage. However, the naturally occurring population of *A. densa* is so highly parasitized that a large buildup of the population seldom occurs. Therefore, its impact on the waterhyacinth population has been limited.

Research conducted by Center (1976)** indicated that, on a small scale, augmented populations of *A. densa* would severly impact waterhyacinth plants under field conditions. Based upon this research, it was speculated that a mass release of the same instar larvae would result in a buildup of the *A. densa* population despite the presence of the parasite populations.

Objectives

The objectives of this research were to:

a. Evaluate the impact of *A. densa* on waterhyacinth through the augmentation of field populations by the mass release of laboratory-reared individuals.

b. Determine the population dynamics of *A. densa*.

Methods

This study was conducted in a canal paralleling U. S. Highway 61

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

** Center, T. D. 1976. The Potential of *Arzama densa* (Lepidoptera: Noctuidae) for the Control of Waterhyacinth with Special Reference to the Ecology of Waterhyacinth, unpublished Ph.D. Dissertation, University of Florida, Gainesville, Fla.

at Norco, Louisiana. Three 0.1-ha plots were established along the canal. To ensure that the same plants were maintained within the plots throughout the study, a series of booms was placed across the canal.

One plot was selected as a control, while the other two served as test plots. The plot designated as the low rate received 10,000 *A. densa* larvae, while the plot designated as the high rate received 30,000 larvae.

The *A. densa* larvae were released on 6 May 1980 after pretreatment data were collected. All of the released organisms were third instar larvae reared on artificial diet at the USDA-SEA Southern Weed Science Laboratory, Stoneville, Mississippi. These third instar larvae were allowed to tunnel into freshly cut petioles and then transported to the test plots in insulated containers. The larvae were released by dispersing the petioles from the bank and from the middle of the plots.

The three plots were monitored at monthly intervals for 5 months. Ten 0.25-m^2 frames were randomly selected from each plot during each sampling period. The following parameters were taken on each plant in the frames except where noted:

Waterhyacinth	
Abundance	Per frame
Biomass	Wet weight per frame
Reproduction	
Plant condition	
Height	Center plant of each frame
No. of petioles	Two plants in each frame

Arthropods	
Population	
Population conditions	
No. of individuals of each life stage (adult, larvae, pupae)	
Spatial distribution	Per frame
Impact on target plants (feeding scars, larval tunnels)	

Results and Discussion

Biomass

The biomass of waterhyacinth in the two test plots was significantly*

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* Significant difference noted in this paper = $P < 0.05$.

lower than in the control plot 1 month after the release of *A. densa* (Figure 1). This significant difference in biomass continued to be maintained between the high rate plot and the control plot for the duration of the study. During the August and September sampling periods, the biomass of the low rate plot increased as compared to the control plot.

Arzama densa

Figure 2 depicts the proportion of plants damaged by *A. densa*. In June, both test plots had a significantly higher proportion of plants damaged than the control plot. This pattern continued for the rest of the study. Fluctuations and changes in the proportion of damaged plants were very similar to changes that occurred in the *A. densa* population. An increased population in the second generation of *A. densa* was not noted in the test plots, and it is speculated that the adults resulting from the released larvae dispersed throughout the vast waterhyacinth mats in the area of the test plots.

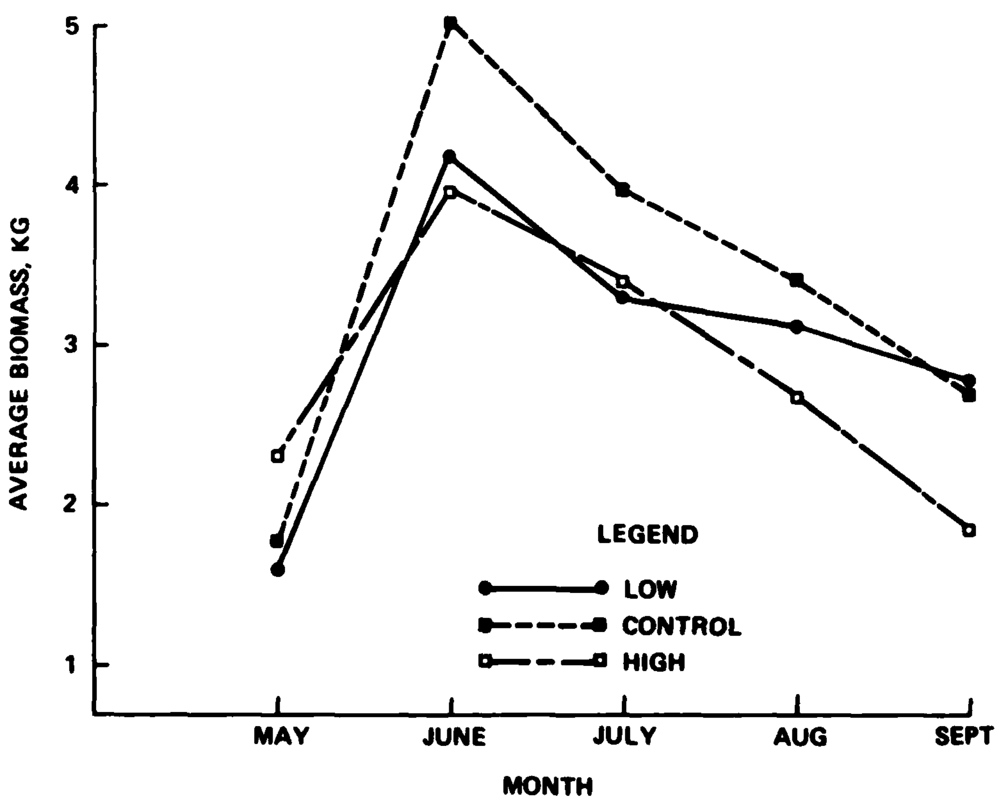

Figure 1. Average waterhyacinth plant biomass in the two test plots after the release of *Arzama densa* larvae on 6 May 1980

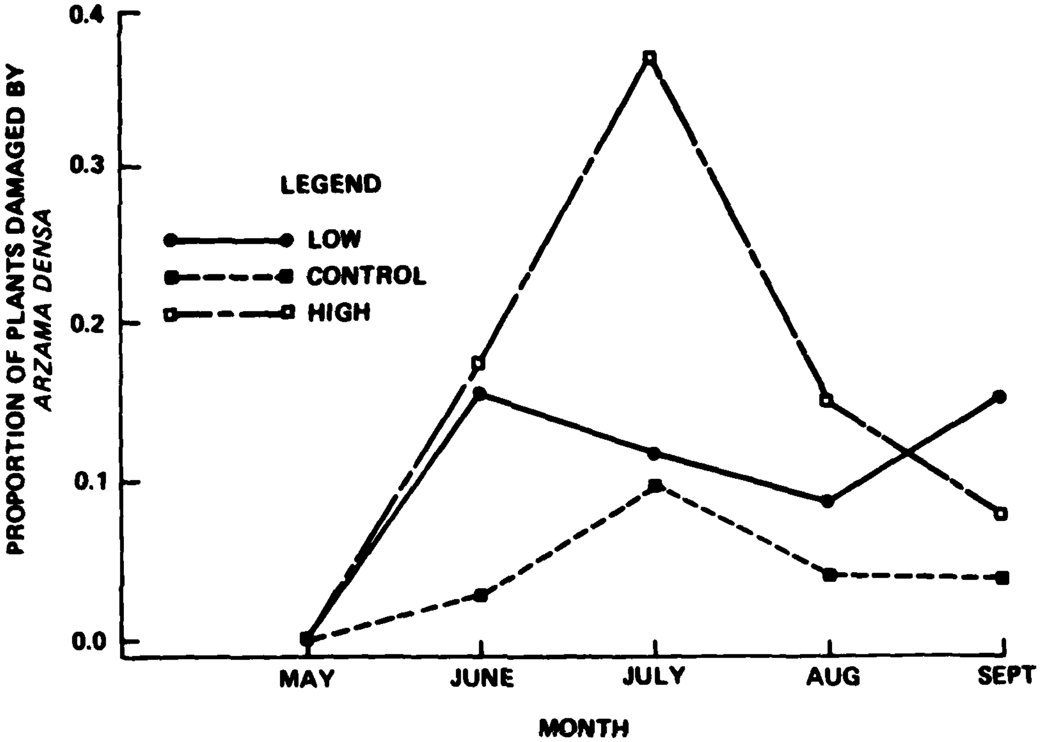

Figure 2. Proportion of waterhyacinth plants damaged by *A. densa*

Density

Waterhyacinth densities in the three plots during the study are presented in Figure 3. In the pretreatment data, the density in the low rate plot was significantly lower than in the other two plots. The difference precluded the performance of a complete statistical analysis on the data set. However, there was a significant reduction in the density of plants in the high rate plot as compared to the control plot following application of the larvae.

Although the densities of plants in the high rate plot and the control plot were the same during September, morphological differences in the plants were noted. Plants in the control plot were larger and had more petioles than plants in the high rate plot, which resulted in a larger biomass in the control plot.

Daughter plants

In the first sampling period after the release of the larvae, there were a significantly greater number of daughter plants present in the test plots as compared to the control plot (Figure 4). This relationship continued between the high rate plot and the control throughout the study. Daughter plant data for the low rate plot showed lower values than the control plot for the July and August sampling periods.

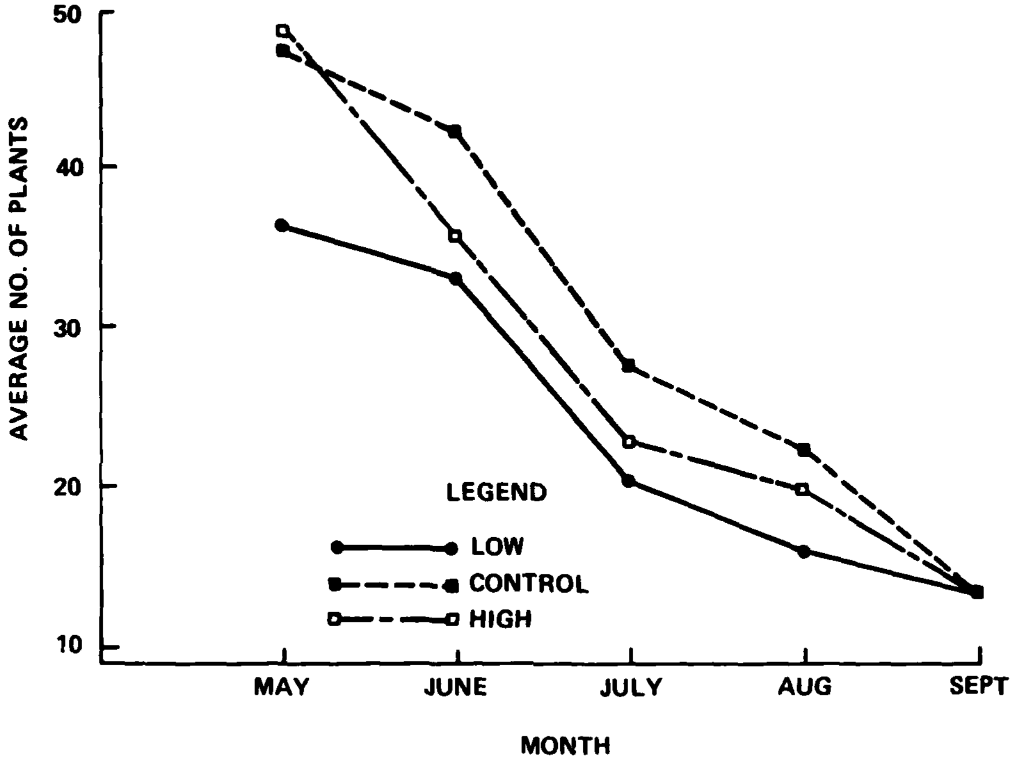

Figure 3. Density of waterhyacinth plants after the release of *A. densa*

The larger number of daughter plants in the test plots was attributed to *A. densa* larvae, which tunneled into and destroyed the crown of the plants. The resultant destruction of the crowns of the plants stimulated the production of daughter plants.

Heights

Plant heights between plots were very similar throughout the study (Figure 5). Significantly lower values were noted for the high rate plot during the July and August sampling periods.

Conclusions

The following conclusions can be drawn from this study:

a. The mass release of *A. densa*, in this study, resulted in a significant reduction in the biomass of waterhyacinth.

b. The mass release of *A. densa* did not result in the development of significantly greater populations of the insect in the study plots in the second generation.

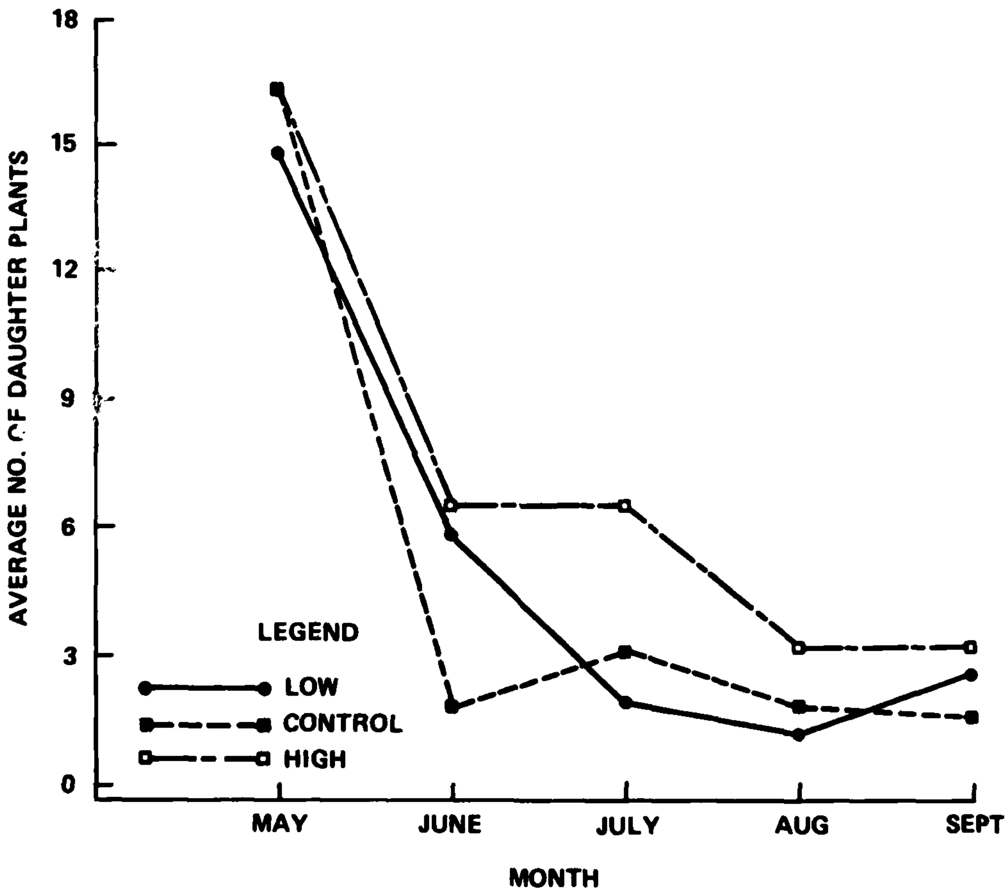

Figure 4. Average number of daughter waterhyacinth plants after the release of *A. densa*

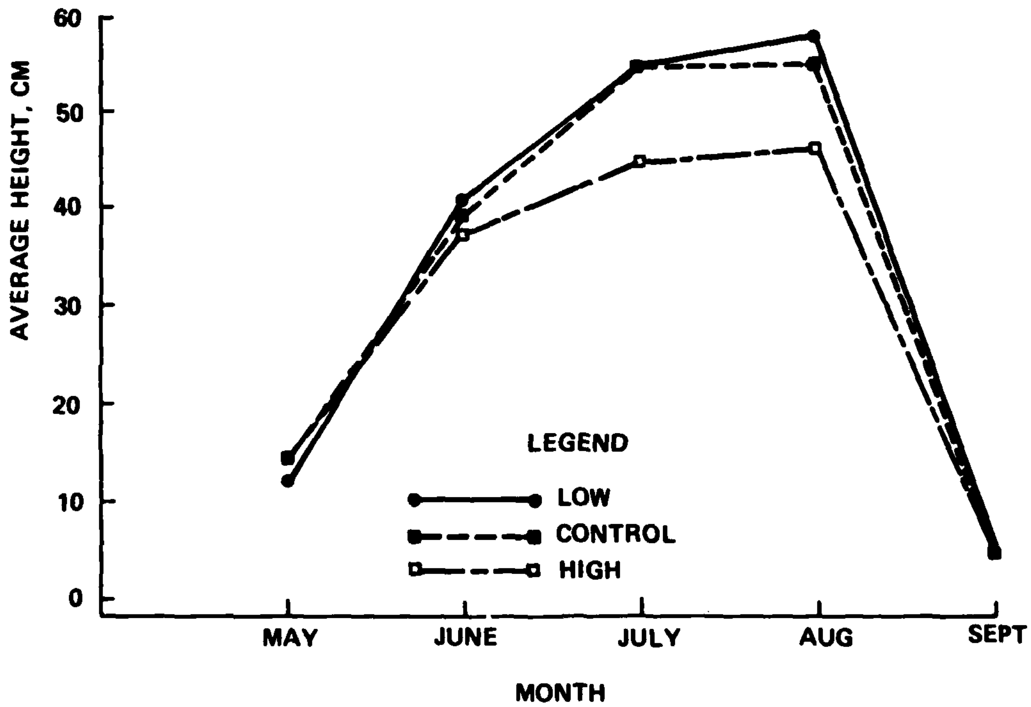

Figure 5. Average waterhyacinth plant height after the release of *A. densa*

LARGE-SCALE OPERATION MANAGEMENT TEST

Large-Scale Field Application of *Cercospora rodmanii*

by

Edwin A. Theriot*

Introduction

The fungus, *Cercospora rodmanii* Conway, is being tested in Louisiana for the biological control of waterhyacinth as part of the LSOMT with insects and pathogens. An experimental formulation of the fungus, which is produced by Abbott Laboratories, Inc. (AL), Chicago, Illinois, is being tested alone and in combination with insects for control of waterhyacinth in areas of Louisiana. In preliminary studies conducted at the WES, it was determined that an application rate of 4×10^6 colony forming units per square metre (CFU/m^2) was sufficient to produce a heavy infestation on waterhyacinth. Using these results and results of studies conducted by the University of Florida and their own toxicological data, AL has obtained an Experimental Use Permit from the Environmental Protection Agency to conduct large-scale field tests with the formulation. The first large-scale field application of the *C. rodmanii* formulation was conducted in April 1980 on a 1.8-ha mat of waterhyacinth in a canal in southeastern Louisiana.

Objectives

The objectives of the large-scale application of *C. rodmanii* are:

a. To determine the most effective combination of *C. rodmanii* with insect agents for the control of waterhyacinth in Louisiana.

b. To develop the framework of an operational system for the routine use of *C. rodmanii* for control of waterhyacinth.

c. To assess the cost of implementation of the resulting operational system.

Procedure

Abbot Laboratories provided the WES with 90.8 kg of the formulation,

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

which had a viability of 1×10^6 CFU/g. At that viability, an application rate of approximately 40.4 kg/ha of the formulation was required to achieve an actual rate of 4×10^6 CFU/m^2. However, AL has produced the formulation with four times that viability which would require only 10.1 kg/ha, and they feel confident that they will be able to achieve that higher viability for their final product.

The formulation was applied at 3:00 pm on 8 May 1980 with a fixed-wing aircraft using a standard application boom. The screens and nozzle tips were removed to prevent the equipment from clogging due to the large particle size of the formulation. A total of 72.6 kg was applied to the site. Two trips were made from the airstrip to the site, and 36.3 kg of the formulation was carried on each run. It was mixed in a stainless steel tank in approximately 1000 ℓ of tap water. A surfactant, Ortho X77, was added at a rate of 1.24 ℓ/1000 ℓ to assist in holding the formulation on the leaf surface when applied. The recycling pumps on the aircraft were turned on to prevent the formulation from settling in the application equipment during the loading operation.

When applying the formulation to the site, the pilot flew approximately 2 to 4 m above the waterhyacinth mat. Observers on the ground at the site determined that the pilot had achieved a good, even coverage with the formulation from bank to bank.

Results and Discussion

One month after application, early *C. rodmanii* symptoms were present on plants throughout the site, and the presence of *C. rodmanii* was verified by isolation from plant tissues taken from the site. Three months after application (July 1980), *C. rodmanii* symptoms were most prevalent in the shaded areas along the banks. The low level of visible disease symptoms was due to the abnormally high summer temperatures. Therefore, *Cercospora* sustained itself in the scenescent leaves of the canopy understory and in the cooler, shaded areas. Six months after application (October 1980), plants with dead and dying leaves were abundant throughout the test site. Typical symptoms of *C. rodmanii* were seen, ranging from black punctate leaf spots to coalescence and tip dieback. *Cercospora rodmanii* was isolated and identified from plant tissues collected throughout the test site.

Conclusions

To date, it can be concluded that AL's formulation of *C. rodmanii* is infectious on waterhyacinth in Louisiana and can be applied on a large-scale operational basis using conventional aerial application equipment. *Cercospora rodmanii* should produce a significant reduction in the waterhyacinth population on the test site within the next 2 years.

AQUATIC PLANT CONTROL IN THE PANAMA CANAL

Organisms Impacting Waterhyacinth in the Panama Canal

by

D. R. Sanders, Sr.,* R. F. Theriot,* and E. A. Theriot*

Introduction

Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms) has been a problem in the Panama Canal since 1913, when the Panama Canal became operational.** The problem developed when waterhyacinth plants proliferated in backwater areas and were flushed out into the Chagres River during periods of high rainfall. The resulting rafts of plants occasionally moved into the shipping channels, temporarily obstructing navigation. Although effective measures were taken to keep the rafts of waterhyacinth out of the shipping channels, the waterhyacinth problem has persisted in the Chagres River.

As part of the Panama Canal Aquatic Plant Control Assistance Project initiated in 1977 between the Panama Canal Commission and the APCRP of the WES, a study was conducted from 1978-1980 to determine the complement of organisms impacting waterhyacinth in the Panama Canal and to determine whether or not additional species should be introduced into the Canal for the biocontrol of waterhyacinth.

Methods

Six study sites, four of which were located in the Chagres River, one site in Gatun Lake, and one site at Red Tank Lake, were selected and twenty-four waterhyacinth plants were randomly collected from each site on each of five sampling dates during the study period. Three of the sampling dates occurred during the dry season and two occurred during the rainy season. Each of the resulting 144 plants per sampling date were examined for the presence and feeding activity of arthropods and damage caused by plant pathogens. Rating scales were established to assess the feeding activity of *Neochetina eichhorniae* Warner, *Cornops* sp. Bruner, and *Orthogalumna terebrantis* Wallwork. A similar rating scale was used to record the extent of infection of waterhyacinth leaves by *Acremonium zonatum* (Saw.) Gams. Damage produced by other species of

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** Hearne, J. S. 1966. "The Panama Canal's Aquatic Weed Problem," Hyacinth Control Journal, Vol 5, pp 1-5.

arthropods was also recorded, and sections of leaf tissue exhibiting apparent pathogen symptoms were collected and processed to isolate and identify the causal agent.

Results

Three arthropod species, *N. eichhorniae*, *Cornops* sp., and *O. terebrantis*, were abundant on four of the six study sites on all sampling dates. *Acremonium zonatum* symptoms were abundant on all sites on all sampling dates. No other arthropods or plant pathogens were found to significantly affect waterhyacinth in the Canal.

Temporal variation in the combined activity of these four species on waterhyacinth was considerable. The greatest combined activity of these species occurred in April 1978, while the least combined activity occurred in May 1979. The contribution of *O. terebrantis* to the combined activity increased during the study period, while the contributions of the other species declined. The factor or factors responsible for these results were not determined, although an increased level of herbicide usage during the study period could have resulted in a greater frequency of plant morphotypes preferred by *O. terebrantis*, and a decreased frequency of plant morphotypes preferred by the other species.

Spatial variation in the combined activity of these species on waterhyacinth was more pronounced than the temporal variation. The combined level of activity was greatest in the three sites located nearest the confluence of the Chagres River with the Panama Canal, while the least activity occurred on the more isolated, backwater sites.

To examine relationships between the major species impacting waterhyacinth in the Canal, Spearman's method for determining rank correlation coefficients* was applied to all data for all sampling dates. Significant ($p < 0.05$) positive correlations were found between *N. eichhorniae* and *A. zonatum*, *N. eichhorniae* and *Cornops* sp., and *Cornops* sp. and *A. zonatum* on at least three of the study sites. Significant negative correlations were found between *O. terebrantis* and *N. eichhorniae* and between *Cornops* sp. and *O. terebrantis* on one site.

Conclusions

Although the four above-mentioned species were very active on waterhyacinth in the Panama Canal, they did not impact waterhyacinth sufficiently to produce a controlling effect. All of these species primarily affected the older portions of the plants, while the newest tissues

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* Siegel, S. 1956. Nonparametric Statistics for the Behavioral Sciences, McGraw-Hill, New York.

and meristematic zones remained largely unaffected by their activity. It was therefore concluded that the species of arthropods and plant pathogens currently present on waterhyacinth in the Panama Canal could not be expected to provide an adequate level of control, and that additional species should be introduced for the biocontrol of waterhyacinth.

Recommendations

Based on the results of this study, it was recommended that additional species of arthropods and plant pathogens be introduced into the Canal for the biocontrol of waterhyacinth, including *Sameodes albiguttalis* Warren, *Neochetina bruchi* Hustache, *Cercospora rodmanii* Conway, and *Arzama densa* Walker, in that order. Highest priority should be given to the introduction of species (e.g. *S. albiguttalis*) that will attack the newest tissues and meristematic zones of waterhyacinth.

AQUATIC PLANT CONTROL IN THE PANAMA CANAL

Field Evaluation of Endothall in Gatun Lake, Panama

by

H. E. Westerdahl*

Introduction

Aquatic plant infestation of Gatun Lake has steadily increased since completion of canal construction in 1914. Hydrilla (*Hydrilla verticillata* Royle) and waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.) are the major nuisance plant species. Analysis of aerial photographs, representing Gatun Lake during January and March 1977, has shown a slight increase in the areal distribution of these aquatic plants from 5200 to 5400 ha, respectively.

In April 1979, a cooperative field study involving Pennwalt Corporation, Panama Canal Commission (PCC), and WES was initiated in the Frijoles Bay area of Gatun Lake, Panama (Figure 1). The objectives were to:

a. Evaluate the efficacy of Aquathol K and Hydout for hydrilla control.

b. Determine the effects of each formulation on water quality and changes in planktonic community structure.

c. Evaluate the extent of herbicide transport and dispersion in the test area.

d. Determine persistence of herbicide residues in water, sediment, and hydrilla within the test area for supporting registration of Hydout and expansion of the current Federal label for Aquathol K.

Description of Study Area

The upland tropical jungle comprising the drainage area of Frijoles Bay contributes significant inflow during most of the rainy season, i.e., April through November. However, very little runoff occurs prior to June as most of the rainfall is stored by the soil or recycled via absorption by the tropical vegetation and evapotranspiration. The

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

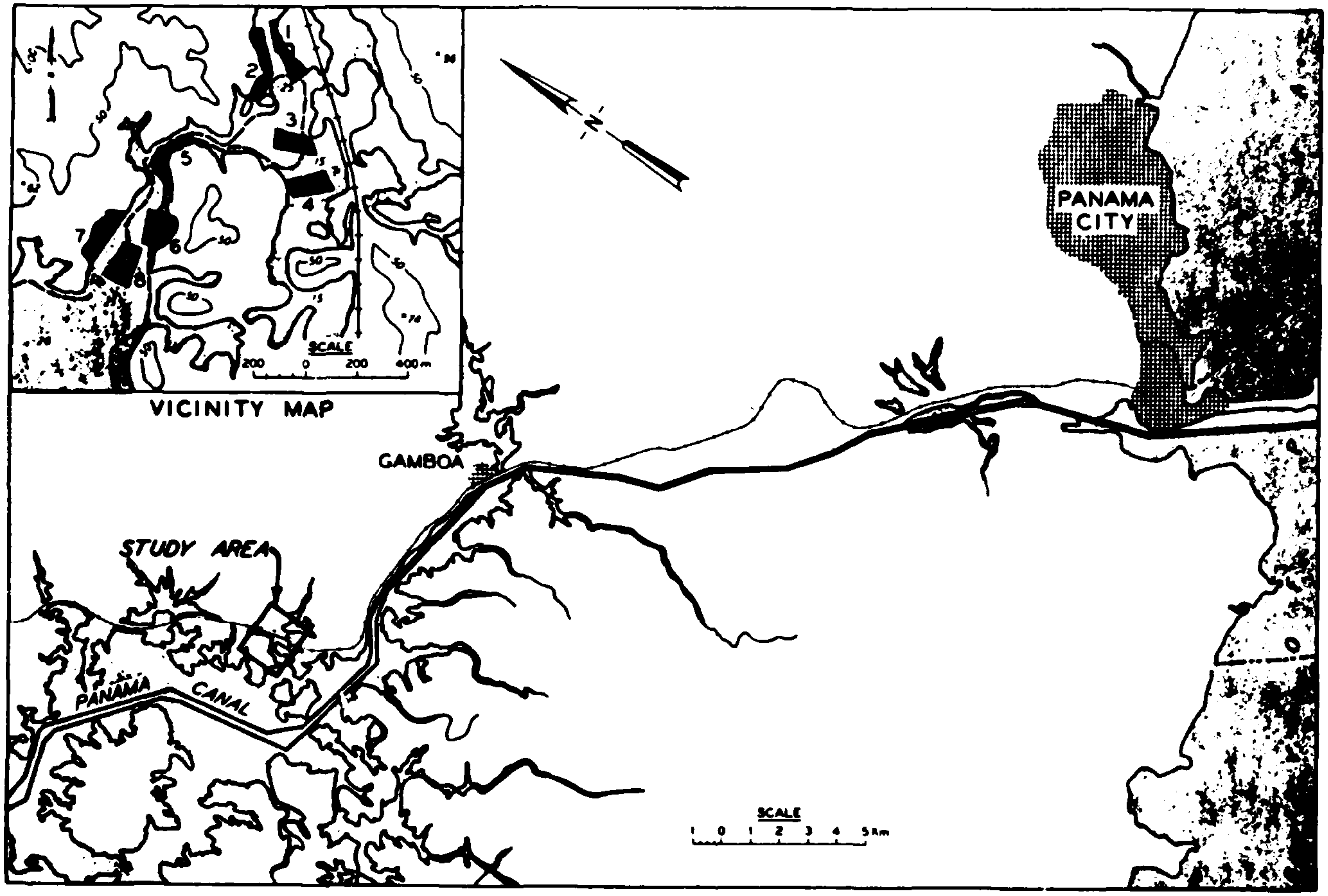

Figure 1. Map of the study area in Gatun Lake, Panama, and vicinity map of El Frijoles Bay showing locations of the treatment plots

test area was considered to be quiescent backwater of Gatun Lake during the first 2 months of this study based on pretest dye studies and post-treatment observations. Elevated water flow through the test area after the first 2 to 3 weeks following treatment was expected to have little effect on herbicide dispersion since the endothall should have been either absorbed by the hydrilla, degraded, or dispersed within that period.

Eight experimental plots, each ranging in area from 1.2 to 1.8 ha and 4 to 8 m in depth, were selected in the Frijoles Bay area of Gatun Lake. Each plot was surveyed to ensure that approximately 90 percent of the water surface area was comprised of hydrilla. To minimize the chance of cross-contamination from plot to plot, the distance between each plot was maximized and, where possible, adjoining plots were separated by the river channel.

Herbicide Application Rates

Three endothall acid equivalent (a.e.) application rates of each endothall formulation, i.e., 27, 34, and 50 kg a.e./ha, were selected for this study (Table 1). These application rates were determined during a preliminary site survey in March 1979. The site survey was performed in a routine manner to represent the typical method employed by most applicators to determine appropriate application rates. Consequently, only qualitative consideration was given to the extent of water flow through the test site area, as well as water temperature, degree of hydrilla infestation, and water depth. Based on a few water depth measurements made during the site survey, the projected endothall concentrations in water at the aforementioned application rates were approximately 1.0, 1.5, and 2.0 ppm a.e., assuming a mean water depth of approximately 3.5 m per treatment plot. These three endothall concentrations were selected to bracket the actual endothall concentration required to achieve hydrilla control in the study area. The specific formulation and application rates were randomly assigned to six of the eight treatment plots (TRT). The remaining two plots were considered as reference plots (REF) for comparison, i.e. REF-4 and -8. Specifically, TRT-1, -6, and -5 received dipotassium endothall at 27, 34, and 50 kg a.e./ha, respectively; and TRT-3, -7, and -2 received the dimethylalkylamine endothall at 27, 34, and 50 kg a.e./ha.

Following analysis of extensive water depth and lake water level data obtained during the study, computations of the static-water volume and mean water depth for each plot showed that the projected estimated treatment rates were in error. Better estimates of initial endothall concentrations in water were computed following analysis of additional data: TRT-1, 0.67 ppm a.e.; TRT-2, 1.06 ppm a.e.; TRT-3, 0.63 ppm a.e.; TRT-5, 1.10 ppm a.e.; TRT-6, 0.65 ppm a.e.; and TRT-7, 0.86 ppm a.e. These endothall concentrations assume that all of the endothall is immediately available throughout the water column following application.

Personnel from the U. S. Department of Agriculture, Aquatic Plant Management Laboratory in Fort Lauderdale, Florida, with assistance from PCC personnel, applied both endothall formulations. The dimethylalkylamine endothall formulation was applied to the respective treatment plots on 18 April 1979 using a blower-type spreader mounted on the bow of a PCC airboat. Half of the formulation was applied on parallel lines across the treatment plots, while the other half was applied on lines perpendicular to the first application. Any remaining herbicide was applied diagonally across the plot. Treatment plots paralleling the shoreline required that the formulation be applied as before except the treatment was initiated along the shoreline. This prevented trapping and possibly killing fish near the shore. Only the hydrilla in the southwest corner of TRT-2 was not adequately treated due to a malfunction in the application equipment during treatment; hence, very little herbicide was applied to this portion of TRT-2. On 19 April 1979, dipotassium endothall was applied approximately 1 m below the water surface using a PCC airboat equipped with a conventional spray pump and four weighted trailing hoses, i.e., two each fore and aft, coupled to a manifold located along the bow. Dense hydrilla cover throughout the treatment plots prevented the trailing hose from delivering the herbicide near the sediment surface. The same treatment procedure, as previously described, was used to ensure uniform areal coverage.

Sampling Program

A simple randomized statistical sampling design was selected since the vegetation appeared to be uniformly distributed over more than 90 percent of the water surface area in all plots. A 15- × 15-m grid pattern was overlaid on scale drawings of each plot and each grid was assigned a number sequentially. Specific sampling locations for each date were selected from a random number table. Approximately 12 locations per hectare were designated for macrophyte biomass and herbicide residue sampling. Subsequent sampling locations for water quality, plankton, and herbicide residue in water, sediment, and hydrilla were randomly selected from the designated macrophyte sampling locations (Table 2). Buffer zones around each plot were sampled approximately 15 m outside the midpoint of each plot boundary. Water samples for plankton, herbicide residue, and other water quality analyses were collected with a Jabsco, Inc., 12-v DC self-priming pump with a weighted hose. Each water sample was taken at 0.3 and 2.0 m below the water surface and 0.5 m above the sediment from different locations within each plot. Similarly, plankton samples were taken randomly from five locations while herbicide residue and water quality samples were taken from three locations within each plot. Sediment samples for endothall residue analyses were obtained by two divers. A 30-cm-long by 5-cm-diam aluminum sampling tube was inserted approximately 15 cm into the sediment and capped; five locations were sampled from each plot. All samples were placed on ice immediately after collection. Those samples for residue analysis were frozen until

analyzed. Plankton samples were chemically preserved until they could be shipped to the United States for analysis.

Herbicide Effects on Hydrilla

Hydrilla in TRT-1, -5, and -6, which were treated with Aquathol K, exhibited pronounced herbicidal effects within approximately 48 to 72 hr posttreatment. The meristematic tissue was translucent and significant defoliation was evident over large areas of the plants. Most of the surface hydrilla mat had dropped below the water surface. Between posttreatment day 7 and 14, the hydrilla biomass had settled to the bottom of the lake. Although most of the plant tissue remained green, damage to the vegetative tissues was extensive. By posttreatment day 21, maximum reduction in hydrilla biomass was evident throughout TRT-1, -6, and -5. However, hydrilla regrowth from the sediment and nodes of hydrilla tissue lying on the bottom surface was also evident at posttreatment day 21. Figure 2 shows the decline and regrowth pattern of hydrilla in TRT-5. Hydrilla in TRT-1 and -6 responded similarly to TRT-5. However, the rate of regrowth was progressively more rapid as the treatment rate was reduced, suggesting that slightly higher treatment rates would increase efficacy and perhaps extend the control period.

Hydout, which was applied to TRT-2, -3, and -7, resulted in a much slower constant decline in hydrilla biomass throughout the 90-days posttreatment. Little evidence of herbicide damage to the hydrilla tissue was noticeable through posttreatment day 21; however, by posttreatment day 49, significant physical damage including defoliation was evident along the entire length of the hydrilla stem. Figure 3 shows the typical decline in hydrilla in TRT-2 over the 90 days following treatment with Hydout.

By statistically comparing hydrilla biomass of each treatment plot to REF-8, the biomass level for all treated plots was significantly lower than REF-8 (Table 3) by posttreatment day 21. By posttreatment day 3, hydrilla biomass in TRT-1 and -5 was statistically lower than REF-8, suggesting that Aquathol K affected the hydrilla much faster than Hydout.

Endothall Residue

Water

Within 24 hr following treatment with Aquathol K to TRT-1, -5, and -6, endothall concentrations were uniform throughout the water column. Moreover, approximately 30 to 60 percent of the endothall remained within the water column in TRT-1, -5, and -6, suggesting both rapid endothall absorption by hydrilla or dispersion of endothall out of the treated area. After approximately 3 days posttreatment, endothall concentrations in each treatment plot had decreased to less than 0.1 ppm a.e. and to less

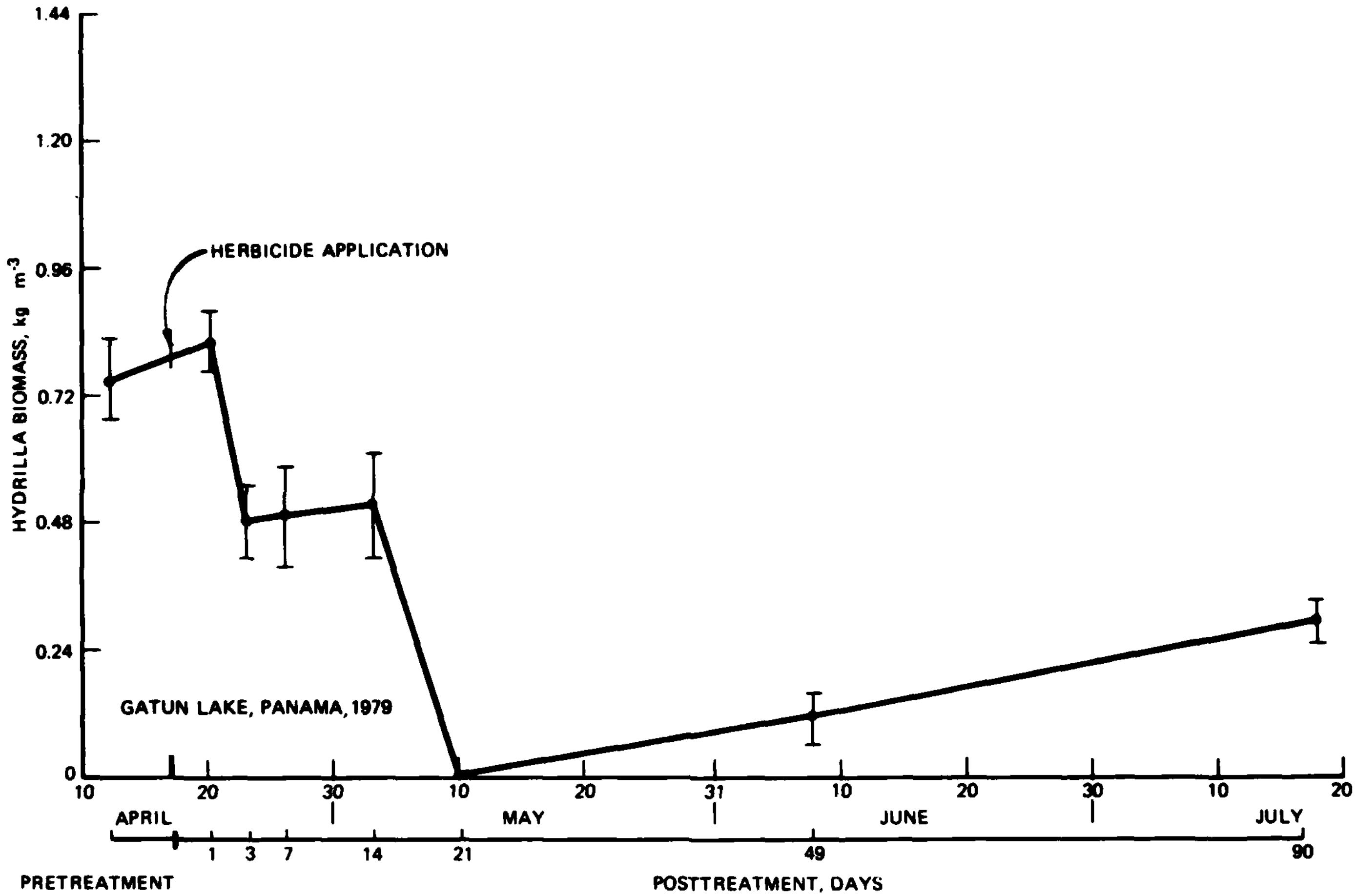

Figure 2. Hydrilla biomass distribution in TRT-5 following application of 1.1 mg a.e/ℓ Aquathol K

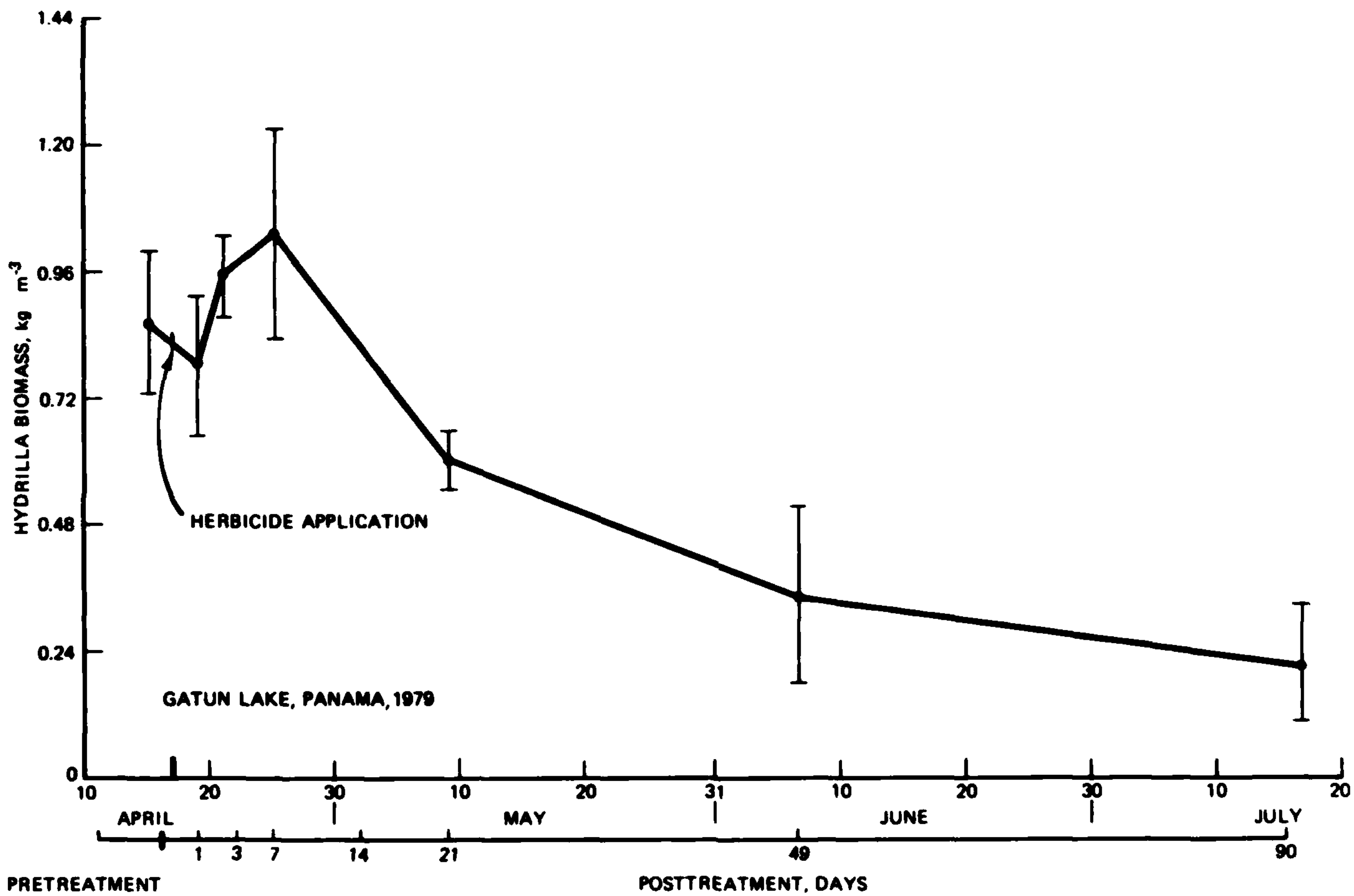

Figure 3. Hydrilla biomass distribution in TRT-2 following application of 1.1 mg a.e/ℓ Hydout

than 0.01 ppm a.e. by posttreatment day 7.

The granular Hydout formulation, which settled onto the hydrilla and sediment following application, released endothall to the water at a much slower rate than the Aquathol K. The release of endothall was even much slower than anticipated. Unlike Aquathol K, less than 30 percent of the estimated initial endothall concentration was available 24 hr after treatment. Furthermore, a maximum endothall concentration of 0.18 ppm a.e. was detected in TRT-2, -3, and -7. The slower release of endothall from the Hydout granules minimized any potential for rapid transport and dispersion of the herbicide from the treated area and provided longer contact time for absorption by hydrilla.

Sediment

Mean endothall concentrations of 0.1, 0.2, and 0.8 ppm a.e. were detected in TRT-1, -6, and -5, respectively, approximately 24 hr following treatment with the Aquathol K liquid. Less than 0.1 ppm a.e. endothall was present in sediment collected from each of the treated plots by posttreatment day 3 and nondetectable levels (less than 0.01 ppm a.e.) were found on posttreatment days 7 and 14. Sediment endothall concentrations were considered transitory in all plots treated with Aquathol K.

Unlike the plots treated with Aquathol K, much higher endothall concentrations were found in sediment samples from TRT-2, -3, and -7. Mean endothall concentrations of 1.0 to 3.0 ppm a.e. remained in all Hydout-treated plots throughout the 21-day posttreatment sampling period. It is not known how long these residues remained in the sediment after day 21. Since the sediment from each plot was comprised of poorly consolidated, amorphous organic muck, the herbicide granules may have sunk into the sediment and gradually released the endothall to the overlying water. The very low endothall concentrations in the water column suggest slow diffusional transport of endothall from the sediment to the overlying water. Moreover, the gradual decline in hydrilla biomass over the 90-day posttreatment period suggests a much longer persistence of endothall in the anaerobic sediment environment. Thus, the use of Hydout may be effective in maintaining long-term hydrilla control.

Hydrilla

Rapid absorption and concentration of endothall into plant tissue was observed in TRT-1, -5, and -6, followed by a gradual decline through posttreatment day 21. The rapid dispersion of the Aquathol K throughout the water column over a 24-hr period permitted thorough surface contact of the endothall with the exposed hydrilla tissues resulting in rapid absorption of the herbicide from the water. The maximum endothall concentrations found in hydrilla tissue ranged from 0.4 to 0.6 ppm a.e. during the first 72 hr following treatment with Aquathol K. Approximately 0.1 to 0.3 ppm a.e. remained in the plant tissue through posttreatment day 21, although the endothall concentrations in water were less than 0.01 ppm a.e. at this time. These data suggest rapid accumulation of endothall by hydrilla followed by slow endothall metabolism in the plant tissue or slow release of endothall from decaying tissue.

Similar endothall concentrations were found in hydrilla treated with the granular Hydout over the same time interval. The maximum endothall concentrations, i.e. 0.4 to 0.6 ppm a.e., occurred between posttreatment days 7 and 14 in TRT-2, -3, and -7. Likewise, approximately 0.1 to 0.3 ppm a.e. remained in the plant tissue on posttreatment day 21, although less than 0.01 ppm a.e. was found in the water.

Water Quality

Gatun Lake is a soft-water tropical lake, i.e. hardness of 35 to 45 mg/ℓ and alkalinity of 45 to 55 mg/ℓ. Table 4 lists the water quality parameters monitored throughout this study. (The PCC analytical laboratory in Miraflores, Panama, performed most of the chemical analyses.)

Only dissolved oxygen (DO) fluctuated in response to the herbicide treatments. An expected nutrient release to the water from decomposing hydrilla was not evident since there was an epiphytic algal bloom following the treatments. The epiphytic community was probably responsible for recycling available organic nitrogen, ammonia nitrogen, and soluble phosphorus as these nutrients were released from decaying hydrilla. The percent DO saturation rapidly declined from 125 percent to approximately 60 percent in the surface 2 m of water in TRT-1, -5, and -6, illustrating the immediate impact of Aquathol K on photosynthetic processes of the epiphytic algae and hydrilla. By posttreatment day 49, the DO levels were near saturation throughout the water column.

A rapid, noticeable change in the DO concentration and percent DO saturation within the surface 2 m of water was not observed in TRT-3 and -7. Only in TRT-2 was there a continuous decline in DO levels within the surface 2 m of water through posttreatment day 21. The gradual DO decline and the qualitative and quantitative changes in hydrilla biomass, as previously described, paralleled each other through posttreatment day 90.

Plankton

In general, plankton communities were only temporarily impacted by the herbicide treatments. The treated plots showed definite reduction in total genera within the Chlorophyceae (green algae) during the 49-day posttreatment study period. Desmids (Conjugatophyceae) became dominant, probably resulting from increased light penetration, whereas the diatoms (Bacillariophyceae) decreased sharply within 3 days posttreatment in TRT-1, -5, and -6 and only gradually in TRT-2, -3, and -7 over the posttreatment study period. A dense bloom of filamentous, mat-forming blue-green (Cyanophyceae) algae, i.e. *Lyngbya* and *Oscillatoria*, was dominant on the decomposing hydrilla tissue from posttreatment day 21 through 49.

The zooplankton community migrated downward with the descending

hydrilla biomass and the attached epiphytic algae to maintain their food supply. Nauplii copepods increased dramatically in size and abundance throughout the study. However, the concentration of zooplankton and relative community structure within the treated plots remained stable throughout the posttreatment study period.

Conclusions and Recommendations

Aquathol K and Hydout were considered to be very effective in controlling hydrilla in Frijoles Bay at Gatun Lake, Panama. The following represent specific conclusions:

a. Aquathol K provided rapid control within 72 hr posttreatment at application rates of 27, 34, and 50 kg a.e./ha, which represent estimated initial endothall concentrations in the water of 0.6 to 1.1 ppm a.e. assuming uniform distribution throughout the water column.

b. Hydout provided control within 14 to 21 days posttreatment at the 34- and 50-kg a.e./ha application rates, which represent estimated initial endothall concentrations in the water of 0.9 to 1.1 ppm a.e. assuming total solubility and uniform distribution throughout the water column.

c. The approximate length of time required for the hydrilla biomass to recover to pretreatment levels was: 4 months for plots treated with Aquathol K and 6 months for plots treated with Hydout. The use of Aquathol K will require three to four applications per year to maintain control in static water environments and probably more often in areas experiencing significant water exchange; whereas, only two to three applications per year would be required for Hydout.

d. The absence of endothall residues in water and sediment approximately 72 hr following treatment with Aquathol K makes this formulation most desirable for treating high use areas, i.e. swimming, beach, and boat marinas.

e. No long-term adverse environmental impacts to nontarget organisms, e.g. phytoplankton and zooplankton, were observed in plots treated with the endothall formulations.

f. Aquathol K can be readily applied using existing PCC equipment. Moreover, it has a long shelflife, i.e. it is unaffected by inclement weather and high humidity. The skin irritation from dust generated during handling and application of Hydout is compounded by the high air temperatures and humidity typical of Panama.

From the results of this field evaluation several recommendations can be made:

a. Combinations of these formulations could effectively prolong the hydrilla control period. Use of Aquathol K to control the initial hydrilla standing crop followed by a reduced concentration of the dimethylalkylamine formulation approximately 3 to 4 weeks later will control germinating propagules and young plant tissue missed by the previous treatment.

b. Since Hydout acts as a slow-release herbicide formulation, its added persistence would be beneficial for use with other contact herbicides.

c. By increasing the concentration of endothall to 1.5 to 2.0 ppm a.e., more thorough destruction of the existing hydrilla tissue is feasible thereby prolonging the hydrilla control period.

d. If only Aquathol K is used, either an adjuvant or polymer should be incorporated to increase endothall's persistence and to subsequently reduce the quantity of herbicide and resulting costs for each treatment, especially in areas of high water exchange.

Table 1

List of Herbicides and Equivalent Treatment Rates for Field Study and Evaluation

Herbicides	Treatment, kg/ha		
	1	2	3
Aquathol K, Aquatic herbicide (liquid)	75	93	140
Current: Federal registration with EPA			
Pending: Amendment allowing increased tolerance limits and immediate use of treated waters for domestic purposes, swimming, and irrigation			
Hydout, Aquatic algicide and herbicide (granular)	269	336	504
Current: State registrations in Alabama, Florida, Georgia, and Texas			
Pending: Application for EPA registration submitted			

Table 2

Number of Sampling Locations for Each Parameter

Parameter	Plot No.							
	1	2	3	4	5	6	7	8
Hydrilla biomass	16	16	16	17	16	18	16	15
Water quality	3	3	3	3	3	3	3	3
Phytoplankton and zooplankton	5	5	5	5	5	5	5	5
Herbicide residue								
Water	3	3	3	3	3	3	3	3
Sediment	4	4	4	4	4	4	4	4
Plant	10	10	10	10	10	10	10	10

Table 3

List of P-Values From the t-Test Comparing Temporal Changes in Hydrilla Biomass of Each Treatment to REF-8

Experimental Plots Compared	Posttreatment, Days					
	P	1	3	21	49	90
REF-8 + TRT-1†	0.329	0.234	0.028*	0.000**	0.001**	0.002**
REF-8 + TRT-6†	0.287	0.568	0.417	0.000**	0.733	0.073*
REF-8 + TRT-5†	0.145	0.202	0.098*	0.000**	0.004**	0.000**
REF-8 + TRT-3††	0.677	0.153	0.441	0.000**	0.857	0.000**
REF-8 + TRT-7††	0.439	0.768	0.517	0.001**	0.058*	0.000**
REF-8 + TRT-2††	0.846	0.178	0.405	0.023*	0.111*	0.000**

* Level of significance at $P < 0.10$.
** Level of significance at $P < 0.008$.
† Aquathol K-treated plots.
†† Hydout-treated plots.

Table 4

Water Quality Parameters Monitored During the Field Evaluation of Aquathol K and Hydout in Gatun Lake, Panama

Water temperature	Turbidity
Water depth	Biochemical oxygen demand
Secchi disk transparency	Total Kjeldahl nitrogen
Color	Ammonia nitrogen
Dissolved oxygen	Total phosphorus
pH	Hardness
Specific conductivity	Alkalinity

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Annual meeting of the Aquatic Plant Control Research Planning and Operations Review (15th : 1980 : Savannah (Ga.))
Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review 17-20 November 1980, Savannah, Georgia / Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station. -- Vicksburg, Miss. : The Station ; Springfield, Va. ; available from NTIS, 1981.
508 p. : ill. ; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; A-81-3)
Cover title.
"October 1981."
"Prepared for Office, Chief of Engineers, U.S. Army."
Final report.
At head of title: Aquatic Plant Control Research Program.

1. Aquatic plants. 2. Aquatic weeds. 3. Research--Management. I. United States. Army. Corps of Engineers. Office of the Chief of Engineers. II. U.S. Army

Annual meeting of the Aquatic Plant Control : ... 1981.
(Card 2)

Engineer Waterways Experiment Station. Environmental Laboratory. III. Aquatic Plant Control Research Program. IV. Title V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; A-81-3.
TA7.W34m no.A-81-3